COMPARATIVE PHYSIOLOGY

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BY

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COMPARATIVE PHYSIOLOGY.

INTRODUCTION.

OF late years there has arisen in the minds of not a few some little confusion as to the absolutely exact meaning of the term Biology. It may be well to point out clearly the two different ways wherein the word is used. Reference to the subjoined table may aid the reader in the comprehension of what follows.

Biology	(*a*) Vegetable=Botany	Anatomy, .	Histology. Morphology.
		Physiology.	
		Classification.	
	(*b*) Animal=Zoology.	Anatomy, .	Histology. Morphology.
		Physiology.	
		Classification.	

Biology is, as far as definition is dependent on derivation, the part of Science dealing with all living things—with all things possessing the power of accommodating their internal conditions to the ever-varying conditions of their environment. Of these living things there are two distinct forms—Plants and Animals. Hence, without in any way attempting in this place to distinguish these two great groups of organized beings, we can divide

Biology into (*a*) Biology in reference to plants, (*b*) Biology in reference to animals. To the former a distinct name is given, Botany. To the latter many give the name Zoology, regarding that science as parallel to Botany, and covering similar ground to that which Botany passes over.

In studying plants there are three classes of facts to be acquired. For example, we can see (1) that the root of a bean plant has a main central axis running down into the ground, with certain small secondary branches. (2) We can learn that the root takes in material from the soil, and gives out salts to the soil. (3) We can discover that all plants with axial roots have leaves with a network of veins and two cotyledons in the embryo. The first of these facts is a structural one. It falls under the province of Anatomy. The second relates to function. It falls under the province of Physiology. The third is connected with the classifying or grouping of plants. To one or other of these three facts every statement in relation to plants can be allied. Under one or other of these three divisions of Botany—Anatomy, which tells us what plants and parts of plants are; Physiology, which tells us what plants and parts of plants do; Classification, which tells us of the relationship between plants—every fact in Vegetable Biology must come.

Turning to the study of animals, similar series of facts are met with. We study the structure of animals (Anatomy), their functions (Physiology), their grouping (Classification).

In the study of the *structure* of living beings, two great classes of facts present themselves. We can acquire knowledge of the larger, easily-seen parts or organs of plants or animals. We can study the shapes of leaves, the number of members in the whorls of a flower, the arrangement of the cavities of the heart, the divisions of the alimentary canal. This is Morphology, or the study of organs. But we can do more than this. With the aid of a knife, microscope, chemical reagents, we can dissect organs, can see their minute structure, can study their very penetralia. This study of tissues is Histology. Anatomy = Morphology + Histology.

Biology, then, should include everything known as to the structure, the functions, the grouping of all plants and of all animals.

But of late the word Biology has been somewhat restricted in its meaning. Professor Huxley and the Senate of the London University are answerable for this. These are great authorities, whom it behoves us to follow reverently. Professor Huxley in his work on *Elementary Biology*, and the Senate of the London University in the Syllabus of the First B.Sc. Examination, seem, as far as we are able to understand them, to include under the name Biology—

(*a*) The study of the *lower* forms of both vegetable and animal life;

(*b*) The study of the *typical* forms of both vegetable and animal life.

Thus, in Professor Huxley's book, he leads the student to the investigation of

Yeast or Torula.
Protococcus.
Proteus animalcule (Amœba).
Bacteria.
Moulds.
Stoneworts.
Bracken (Fern).
The Bean Plant.
Infusoria.
Hydra.
Fresh-water Mussel.
Crayfish.
Frog.

As to the University, the list is much the same, but there is added an account of the principal tissues of the animal body.

It is perhaps open to question whether this later arrangement is really a philosophical one. In the study of Biology there are few more important laws than that of Von Baer,—the law of progress from the general to the special. In the lower plants and animals, all functions are performed by all tissues. The cell wall and contents of a Torula, the sarcode of an Amœba, assimilate, breathe, reproduce. No special part is set aside for the functions of digestion, of respiration, of reproduction. But as we ascend in the scale of living beings, we find particular parts of the plant or animal body reserved for special actions. Axis becomes distinct from appendages; stem begins to transmit, leaves to breathe in the plant. Mouth and alimentary canal are marked off from the rest of the body; certain definite parts of the surface take on themselves the function of breathing in the animal. Differentiation progresses, until in the performance of every function there is a definite region of the body concerned.

Von Baer's law holds generally in scientific nomenclature. A few years back, the general name Natural History was much in vogue; and when a man studied minerals, plants, and animals, he was a student of Natural History. By degrees, however, differentiation took place, and men began to turn their attention specially to Geology, or to Botany, or to Comparative Anatomy. A curious transition stage between the old Natural History and the present three great sciences (each whereof is gradually undergoing further division) is shown by the use of the words Natural History in the preface to Huxley and Martin's *Elementary Biology*. Therein Natural History is said to be synonymous with Biology, *i.e.* with the study of living beings only.

The present use of the term Biology seems to be the result of a reverse action to that so constantly occurring, the verbal expression whereof is the law of Von Baer. We seem here to have passed from more special names to a more general one.

In favour of the same transition, it may be urged that the aim of Science is to arrive at larger generalizations, and that the substitution of the single word Biology for the two names Botany and Zoology, is an advance: that under Biology we are to range all wide facts that are true of all living things. It must not be forgotten, however, that we are obliged still to retain the sciences of Botany, of Comparative Anatomy and Physiology, and of Zoology. More abstract, however, than all these, an embodiment of generalizations founded on the facts of all these, is Biology.

It is not possible to study one branch of Biological Science without acquaintance with others. In the following pages an attempt will be made to systematize the known facts in relation to the physiology of animals. The main object of study will be Comparative Physiology. But, as it is not possible to investigate a function without a knowledge of the organ performing it, Comparative Anatomy will also be studied; and as special animals and special classes will have to be referred to, the leading facts in the classification of animals must be discussed more than once. For the full comprehension of facts in regard to animals, the structure and functions of plants must be spoken of, and the domain of Botany will be trenched upon. Especially will the understanding of the chief principles of classification be necessary. A table is therefore subjoined, showing the system to be used in this book :—

	Sub-Kingdom.		Class.	Example.
ANIMALIA.	PROTOZOA,		*Gregarinida,*	Gregarine.
			Rhizopoda,	Amœba. Foraminifera.
			Infusoria,	Vorticella.
	CŒLENTERATA,		*Porifera,*	Sponge.
			Hydrozoa,	Hydra.
			Actinozoa,	Sea Anemone.
	MOLLUSCA,	Atriophora,	*Polyzoa,*	Filustra.
			Ascidioida,	Ascidia.
			Brachiopoda,	Terebratula.
		Branchiophora,	*Lamellibranchiata,*	Oyster.
			Gasteropoda,	Snail.
			Pteropoda,	Haliotis.
			Cephalopoda,	Cuttle-fish.
	ANNULOSA,	Pseudhæmata,	*Scolecida,*	Tape-worm.
			Echinodermata,	Echinus.
			Gephyrea,	Sipunculus.
			Annelida,	Earthworm.
		Arthropoda,	*Arachnida,*	Spider.
			Myriapoda,	Centipede.
			Insecta,	Fly.
			Crustacea,	Lobster.
	VERTEBRATA,		*Pisces,*	Salmon.
			Amphibia,	Frog.
			Reptilia,	Snake.
			Aves,	Pigeon.
			Mammalia,	Horse.

All our facts and theories will tend to the great ends of gaining generalizations as to all living things, of arriving at statements that can be predicated of all plants and animals, of building up a true science of living things.

It has been said that the verbal expression of one of the most important generalizations in Biology is called Von Baer's Law. It is the law of 'progress from the general to the special.' All functions of the lowest animals and plants are performed indifferently by all parts of the body. No special regions are marked off for special functions. As we ascend in either the Vegetable or the Animal Kingdom, certain parts of the body become marked off for particular functions. One area is restricted to Digestion, another to Circulation, a third to Reproduction. The more highly organized the being, the more complete is the division of its body into distinct organs, each with a special action. It is designed in this volume to trace out, in relation to the Animal Kingdom, the gradual steps whereby any given function, at first performed indifferently by any portion of the body, becomes restricted to particular portions with an ever-increasing specialization of the organs concerned in it.

The order wherein the various functions and organs will be considered in the following pages is as follows :—(1) Digestion, or the preparation of the food. (2) Absorption of digested food. (3) Circulation of the blood. (4) Respiration, or the purification of the gases of the blood. (5) Secretion, or the separation of liquids and solids from the blood. (6) The Nervous System. (7) The Sense Organs. (8) The Motor Organs. It will not be possible within the limits of this book to discuss the advance in specialization in the functions of Reproduction and Development.

CHAPTER I.

DIGESTION IN PROTOZOA AND CŒLENTERATA.

THE first function to be considered is *Digestion.*

When it is remembered that we have to trace the history of digestion upwards from its most general form, it will be seen how difficult it is to give any definition of the word to include all cases. Only an approximation can be hoped for. Such an approximation may be found in the statement that digestion is the process whereby food is taken into the organism and made fit to become part thereof.

1. Protozoa—(1) Gregarina.—This animal is found infesting the interior of certain invertebrates, such as earthworms and cockroaches. It absorbs food by every part of its surface, and probably gives out material at every part of its surface. Looking at these facts, and at the fact that the food so absorbed is in some cases at least already partially digested by the animal in which the Gregarine is resident, this may be regarded as one of the simplest cases of digestion in the Animal Kingdom. It may be well to state here, once for all, that we shall not find the gradual specialization of different functions following the same lines in the animal series. Nor will the advance of particular functions keep pace with the advance in

structure. In absolute structure, for instance, the Gregarine ranks higher than some of the beings referred to below.

(2) Amœba.—This well-known jelly-like Rhizopod, met with in the waters of ponds and aquaria, thrusts out from any part of its body extensions known as *pseudopodia* towards any food particles that may be in its vicinity, seizes them, and then retracting its pseudopodia, draws them into the substance of its body, and with them the food particles. Within the body, the food thus taken in has its nutritive matter gradually extracted by the protoplasm or sarcode, whereof the creature consists; while the indigestible residue passes out of the body at any point. It is to be noted here, that *any* part of the body may be protruded as pseudopodia, that the food particles in passing through the sarcode take no definite course, that the portions of them not absorbed are extruded at no definite region. Yet here is an advance upon the Gregarine, as *a* part of the body is extended into pseudopodia, but it is a matter of indifference which particular part. A mouth region and an anal region are marked off for each particular particle of food, but there is no mouth and there is no anus.

(3) Pamphagus.—A Rhizopod of similar structure to the Amœba, but the pseudopodia are given out from one particular region only of the body. So is it with Difflugia and Arcella, two simple Rhizopods that differ from Amœba and Pamphagus in having an external covering. The pseudopodia are extruded only from the single aperture present in each such external covering.

(4) Foraminifera.—These complex Rhizopods may be looked upon as colonies of amœbiform

creatures all connected with each other, and surrounded by a complex shell. Two phases of digestion present themselves here: (*a*) Each division of the shell is perforated by many apertures, through which the pseudopodia of the particular amœbiform creature dwelling within that division are protruded. (*b*) The shell is not perforated, but the food for the whole colony is seized and taken in by pseudopodia given off by the individual segment found in the last-formed and therefore most free cavity of the shell.

(5) Infusoria.—The well-known inhabitants ot water in which vegetable matter has been for any length of time show a very distinct advance. There is in these, for the first time, an absolute and constant aperture—the mouth. Towards this, food particles are swept by the action of the cilia, or delicate, structureless, vibratile extensions of the body. Food entering the mouth passes down a distinct tube—the gullet or œsophagus. This œsophagus does not, however, dilate into a stomach, nor indeed are there any other parts of the alimentary canal except mouth and œsophagus. The latter is closed below, or rather clogged by the sarcode of which the body still consists. Through this sarcode passes the food that has been ingested; but it has a very definite shape, and passes in a very definite direction. At the bottom of the œsophagus the food is shaped into pellets, each surrounded by a layer of water. These are called food vacuoles, the watery part giving them the appearance of partially empty spaces. The older food vacuoles, as new ones are formed, are pushed on into the interior of the body. The direction in which they move is, as has been said, definite. Each is driven on by its successors

just beneath the outer layers of the body, and so makes a complete circuit of the Infusorium. The food pellets become smaller and smaller the longer they have been in the body, and, finally, the indigestible residue passes out in a similar fashion to that met with in the Amœba. There is no actual opening; but there is a very distinctly-marked *region* where this extrusion occurs. Here, then, is a mouth, œsophagus, a distinct course for the food, though there is no intestine, and an anal region though no persistent opening.

2. Cœlenterata—(1) Hydra.—This being, found on the roots of duckweed, is a simple bag fixed by the base and open at the other extremity. The opening, which is surrounded by tentacles, is the mouth, and leads into a single cavity. This single cavity in the interior of the creature is at once the general cavity of the body, or somatic cavity, and the digestive cavity. It may be necessary here to make quite plain what is meant by the terms 'somatic cavity' and 'digestive cavity,' as much confusion appears to exist in many minds as to the meaning of the phrases. The somatic or body cavity is the cavity contained within the general body wall, and would remain empty if all the internal organs were removed. In the higher animals this general cavity is traversed by a tube of greater or less complexity, communicating with the exterior, but completely shut off from the general cavity; this tube encloses the digestive cavity.

In the Hydra the body contains but one single cavity. Clearly this is a somatic one; but inasmuch as food is constantly being introduced into it by the mouth, it is also a gastric or digestive one. The two cavities, distinct in higher animals, are here fused into one. Food taken into the creature has the nutritive portion of it absorbed by the body walls, and the non-nutritive probably ejected by the mouth. Here is a complete mouth and alimentary canal; but the latter is still one with, and not cut off from, the general cavity of the body.

(2) Sea Anemone.—This animal, found in large numbers adhering to the rocks on our own coasts, resembles the Hydra in being fixed by its base, and in having at the other extremity a mouth surrounded by tentacles. It is, however, no longer a simple bag, but a double one. It consists of one bag suspended within another. The one is the digestive cavity, the other is the somatic. Food passes through the mouth directly into the digestive cavity, which presents no traces of division of any kind. It is a simple tube. Below, this digestive cavity opens into the general body cavity in which it is suspended. In the Hydra the two cavities are one. In the Sea Anemone they are distinct from, but communicate with, each other. The hollow tentacles surrounding the mouth are elevations of the roof of the somatic cavity, and are perforated at their free apices. Food entering the mouth undergoes digestion in the suspended alimentary canal. The results of its digestion either transude through the walls of the alimentary canal into the surrounding body cavity, or pass directly from the one to the other by the aperture in the base of the former. Such portions as are not digested quit the body, not at one definite aperture, but at the perforated apices of the tentacles.

So far we have seen the function of digestion performed by the whole of the body (Gregarine); by any accidental portion thereof (*Rhizopoda*); by a mouth, œsophagus, and tolerably definite portion of the sarcode of the body, without, however (after the œsophagus), any distinct tube (*Infusoria*); by a mouth and distinct alimentary canal, one with the body cavity (Hydra); by a mouth and distinct alimentary canal suspended in, distinct from, but communicating with the body cavity (Sea Anemone).

CHAPTER II.

ON DIGESTION IN THE MOLLUSCA AND ANNULOSA.

IT will not be advisable to deal, as in the first chapter, with a series of animals whereof the whole digestive apparatus shows an ever-increasing complexity. It will be better to take the digestive apparatus itself, and to note in what animals that apparatus shows advance in one direction, in what animals it shows advance in another. Some creatures present improvement in structure and in function along one particular line, whilst others have specialization of an entirely different part of the alimentary canal. It is therefore often difficult, or even impossible, to say positively whether the *whole* digestive apparatus of a given animal is of a higher or lower order than that of some other animal.

A. Alimentary Canal still communicating with the Body Cavity.—Above the Sea Anemone in the animal series, this communication between the digestive and the somatic cavities is very rare. Striking instances thereof are presented by Ascidia and other members of the class Ascidioida. The alimentary canal in these animals is sufficiently complex, but the dilated pharynx is perforated. Thus its interior is in communication with the general cavity of the body wherein the digestive tube is suspended. Further, the intestine of Ascidioida does not open directly on the exterior of the body, but opens into a chamber known as the atrial. This atrial chamber does communicate with the exterior of the body.

B. Alimentary Canal communicating with Organs concerned in Functions other than Digestion.—Three principal cases present themselves:—(*a*) With the absorptive apparatus. The function of absorption in the Invertebrata is never carried on by a distinct set of vessels. In the lower Mollusca and Annulosa, the walls of the alimentary canal absorb the digested food. In the higher, the blood-vessels in the walls of the alimentary canal absorb the digested food. In both cases, the two functions of digestion and absorption are not completely differentiated from each other. The details of the advance in complexity of the absorptive function will be worked out more fully in succeeding pages. (*b*) With the circulating apparatus. The organs of digestion and of circulation in some cases are in connection. The alimentary canal of Brachiopoda and that of Lamellibranchiata perforate the heart. That of Haliotis, one of the class *Gasteropoda*, is embraced by but does not perforate the heart. (*c*) With the respiratory apparatus. (i.) The pharynx or upper end of the alimentary canal of Ascidia, referred to above, is connected with respiration as well as digestion. It is perforated. It is richly supplied with blood-vessels. The margins of the perforations are ciliated, *i.e.* provided with very fine motile hairs or cilia. Through these apertures water, air-laden, is ever rushing. Thus the blood in the vessels of the pharynx is brought into relation with the air in the water. Here is an organ presenting a fusion of the functions of digestion and respiration. (ii.) In Rotifera or the Wheel-animalcules, the *lower* end of the alimentary canal has connected with it the tubes of the water-vascular or respiratory apparatus.

C. Alimentary Canal closed at one end.—In some Invertebrata the intestine is blind. A mouth or anterior opening is present. There is no anus or posterior aperture. Two orders of the class *Scolecida*, viz. the Trematoda, whereof Distoma is an example, and the Turbellaria, illustrated by Planaria, and the Ophiurida of the class *Echinodermata*, have an alimentary canal closed at the end.

D. Reversions.—Before turning to the consideration of individual portions of the digestive canal, attention must be called to certain curious reversions to a very low type of digestion, met with in animals comparatively high in the scale of being. Some Entozoa, as the tape-worm, have no digestive organs. They live, as *Gregarinida* live, by imbibition of the partly digested food of the animals they infest. The males of some Rotifera are also destitute of any digestive apparatus. The whole of their brief life is devoted to reproduction.

E. Mastication.—Turning to the account of specialized parts of the alimentary canal, it is necessary to refer first to those arrangements whose purpose is the comminution of the food, the breaking up into smaller portions of the materials to be digested. The general term *mastication* may be employed here. (*a*) Perhaps the least specialized form of masticatory apparatus is the gizzard, though this organ is met with in animals ranking high in the animal series. A gizzard may be defined as an exceedingly muscular stomach. The walls of all dilatations of the alimentary canal will be muscular. Let the walls of a particular dilatation be very muscular and often provided with specially hard tendinous or even calcareous or silicious regions, and the dilatation is a gizzard. Such an organ is met with in the *Polyzoa*, *Gasteropoda*, *Cephalopoda*, Rotifera, Earthworm, and the higher *Insecta*. (*b*) Hardenings of the mouth-lining or buccal mucous membrane form a more specialized apparatus for mastication. The structures concerned in breaking up the food have now assigned to them a definite position at the beginning of the digestive tube. They are separated from the stomach. In the *Annelida*, as the earthworm, tube-worm, leech, the 'jaws' are hardened parts of the mouth mucous membrane. If they can be compared with any structure in the higher animals, it is with the teeth of the latter, which are also developed from epithelial membranes. That this is a low form of masticatory apparatus is shown by the fact that the number of 'jaws' may vary on opposite sides of the same mouth. (*c*) The exceedingly complex masticatory apparatus of Echinus, with its five jaws, each traversed by a tooth, and all moved by an elaborate arrangement of muscles, is still, probably, only a very specialized hardening of epithelial membrane. (*d*) A similar statement may be made in relation to the odontophore of the higher *Mollusca*. This structure, with its cartilaginous support, its long elastic strap, its transverse rows of teeth, seems to combine, to some extent, the functions of teeth and of tongue. (*e*) The mouths of the higher *Annulosa* present a higher type of masticatory apparatus. Their jaws are appendages of the body-segments. They are modified limbs. (i.) The simplest condition is that met with in the *Myriapoda*, as the Centipede. A small labrum above the mouth-opening, a pair of mandibles or hard, crushing jaws, a labium below the mouth-opening, with side lobes. (ii.) The *Arachnida* (spider and scorpion) have labrum and mandibles, and two pairs of more delicate jaws, known as maxillæ. These are the side lobes of the labium of Centipede specialized into distinct lateral jaws. In *Arachnida*, the mandibles are extended into prehensile and offensive claws. The maxillæ in spider are related in a remarkable manner to the function of reproduction. The specialization is therefore incomplete. (iii.) *Crustacea*, the lobster, have a labrum, two mandibles, four maxillæ (the second pair representative of the split labium of *Myriapoda*), and three pairs of feet-jaws (maxillipedes). These last represent the six legs of *Insecta*. The somites, which in the latter bear motor organs, carry in the *Crustacea* organs that serve for mastication, but that are in structure closely allied to the true legs on the succeeding somites. (iv.) In the *Insecta*, the labrum, labium, mandibles, maxillæ, are all met with, and present numberless modifications far too complex to be even mentioned here. All these modifications are, in the main, subservient to the functions of taking in or crushing food. (*f*) Finally, whilst all the jaws mentioned above move in a horizontal plane, in the cuttle-fish (*Cephalopoda*) the jaws move in a vertical plane.

F. Stomach.—A dilatation of the alimentary canal is a stomach. No such dilatation is found in some of the *Echinodermata*, and a very slight one in the *Ascidioida*. Forms of stomach.—(*a*) The most necessary and constant form of stomach is an expansion of the alimentary canal, where the food is delayed, and whereinto digestive fluids are poured. This is the true stomach, present in the majority of MOLLUSCA and ANNULOSA, with the exceptions just mentioned. (*b*) The Gizzard.—Reference has been made to this. (*c*) The Crop.—An expansion of the alimentary canal, very generally a lateral one, whereinto no digestive fluid is poured. The crop serves to store up the rapidly-swallowed food until time is afforded for that food to be passed on to the true stomach. The crop does not digest. It is seen in the higher orders of *Insecta*.

G. The Intestine.—The narrowed part of the alimentary canal succeeding the stomach. (*a*) It is straight and without convolutions in many MOLLUSCA and in most of the ANNULOSA, as the Star-fish, the Scorpion, the Centipede, and even the *Crustacea*. (*b*) It presents convolutions in some. These cases are more particularly met with in the MOLLUSCA, in which group the digestive apparatus on the whole presents a higher type than that seen in the ANNULOSA. Even the lower MOLLUSCA have a flexure or bend in the intestine. (*c*) Lastly, the distinction between the small and large intestine, a distinction founded on their relative diameters, not on their relative lengths, is observable in the *Insecta* and in many MOLLUSCA.

CHAPTER III.

ON DIGESTION IN THE VERTEBRATA.

Pisces, *Amphibia*, *Reptilia*.

THE structure of the digestive apparatus in the sub-kingdom Vertebrata remains for consideration. It will be best to study the individual classes of that sub-kingdom one after another. It will be observed that, as we ascend through this the highest group of the kingdom Animalia, we shall meet with that ever-increasing heterogeneity, and also that ever-increasing definiteness, that Mr. Herbert Spencer has shown to be the accompaniments of evolution. We shall find more parts appearing in the digestive apparatus, and we shall find each of them more and more distinctly marked off from its fellows, both structurally and functionally. Different kinds of teeth will replace a dental system whose members are all exact counterparts one of the other. The simple intestine will become differentiated into several special regions. Each kind of tooth will attack the food in the process of mastication in its own special way. Each region of the intestine will have its own distinct office in the digestion of the food.

(1) *Pisces.*—A. Teeth.—The teeth are nearly all conical, are distributed over the surface of the interior of the mouth and pharynx, and are not imbedded in sockets. B. Stomach.—In some fish

the stomach is not really distinct from the œsophagus. In the majority it is wide and sac-like, and in scarcely any is it very clearly marked off from the preceding and succeeding parts of the alimentary canal. C. Small Intestine.—Comparatively short. At its commencement are several blind tubes (cæca) opening into the intestine directly. From their proximity to the pyloric end of the stomach, they are known as the pyloric cæca. In many fish the surface of the intestine is increased by the extension of its internal mucous coat into a fold running spirally along the wall of the intestine, and called the spiral valve. There are scarcely any villi or minute elevations of the mucous coat. The spiral valve seems to represent a less specialized method of increasing the absorptive surface than the villi met with in higher classes. Lastly, the mesentery, or special fold of peritoneum slinging the intestine on to the spinal column, is much reduced compared with that of higher vertebrates, and sometimes in the peritoneum are openings rendering that serous membrane no longer a closed sac, but putting it into communication with the exterior of the body. D. Large Intestine.—Short; only marked off from the small by a constriction and an internal valvular fold; without a cæcum. In fact, the large intestine is homologous with the rectum alone of *Mammalia.* It ends very frequently, but not universally, in a cloaca, *i.e.* its final portion has opening into it the ducts of the renal and reproductive organs. The cloacal outlet or anus varies much in position. It is at times placed very far forwards in the body. E. Glands.—(a) Salivary glands wanting. (b) Pancreas. The pyloric appendages are secretory. They are sometimes spoken of as representatives of a pancreas, but there is a rudimentary gland, which, from its position, and the relationship of its duct to that of the liver and to the commencement of the small intestine, is probably the true pancreas. (c) Liver; a mere cæcum in the lowest members of the class; a well-defined conglomerate organ in the majority, with portal and arterial circulations, hepatic duct, gall-bladder, and cystic duct.

(2) Amphibia.—A. Teeth may be absent or very rudimentary. When they are present, they are ankylosed to the bone beneath. They are distributed over a great many more bones than the superior and inferior jawbones and the pre-maxillæ; but whilst that is the case, it is to be noticed that the bones liable to support teeth are not so numerous as those carrying dental appendages in *Pisces*. B. Stomach.—Still not very plainly marked off from the rest of the alimentary canal. C. Small Intestine.—Short in the adult Amphibian; longer and more convoluted in the larvæ. This change has relation to the different kinds of food eaten in the two stages of life. The larvæ (tadpoles, for example) are vegetable feeders. The adults are animal feeders. It takes less time and trouble to turn animal matter into new animal matter than to transform vegetable structures into animal tissues. Therefore the intestines of herbivorous creatures are relatively longer and more complex than are those of carnivorous. The internal lining does not exhibit villi, but it has longitudinal folds or rugæ, undulatory, but not spiral, in their course. D. Large Intestine.—Without any cæcum. The colon is now distinct from the rectum. There is a cloaca whereinto open the allantois, oviducts or spermducts, and ureters. E. Glands.—(a) Salivary wanting. (b) Pancreas; a very distinctly-marked organ. (c) Liver; large, with gall-bladder.

(3) *Reptilia.*—A. Teeth.—Distributed over a much more restricted area. In the highest order, Crocodilia, only the maxillæ, pre-maxillæ, and the dentary part of the mandible carry teeth. Their crowns vary much in appearance. In most *Reptilia* the teeth ankylose after a time with the bones supporting them, but the Crocodilia have sockets or alveoli. In Ophidia (serpents) there occurs a curious fusion of another function with that of mastication, when certain teeth are found connected with a poison apparatus. B. Stomach.—Transitions from that of Ophidia, a slight uncurved œsophageal dilatation, to that of the crocodile. The gastric cavity of the latter is really double. Its first larger part is very muscular. It is, in fact, a gizzard. Often is it found to contain stones that are probably of use in crushing the food. The smaller pyloric portion is possibly the more truly digestive cavity. C. Small Intestine.—Supported by a distinct mesentery. There are, however, no omenta or folds of the peritoneum passing from the stomach to viscera in its neighbourhood. The peritoneum is still not a perfectly-closed serous membrane in many. Jejunum and ileum are sufficiently plain, but only a duodenal *region* exists, save in crocodiles, where there is a distinct duodenum. Rugæ are again present, and also clearly-marked villi. D. Large Intestine.—Short, straight; no long cæcal appendages open into it. The cæcum is in the direct line of the alimentary canal, not a diverticulum thereof. The rectum ends in a cloaca. E. Glands.—(a) Salivary are now quite evident in all; but they are usually placed in the tongue, so they are not quite so specialized as in the highest classes. (b) Pancreas; present, with often more than one duct. (c) Liver; with gall-bladder.

CHAPTER IV.

ON DIGESTION IN VERTEBRATA.

Aves, Mammalia.

THE function of Digestion in the classes *Aves* and *Mammalia* has to be studied. In dealing with the higher class of the two, we shall find it possible to study Digestion under the heads of certain distinct processes, such as Mastication, Insalivation, Deglutition. It is not quite feasible to study the Digestion of birds in this way. The various stages of food preparation are not quite sufficiently clearly marked off one from the other. Dealing with *Pisces*, *Amphibia*, *Reptilia*, we stated our facts under such heads as Teeth, Stomach, Small Intestine. Dealing with *Mammalia*, we purpose stating our facts under such heads as those given above. Investigating the intermediate class, *Aves*, we must adopt divisions partly anatomical, partly physiological. Even in the construction of books, transition stages are forced upon us.

(1) *Aves.*—A. Beak.—Horny, without teeth. The infinitely various forms of beak met with in birds are deeply interesting to the evolutionist. Probably from the same primordial organ have been evolved, under the careful selection of nature, all these numberless varieties. Whilst the beak is rather a prehensile than a masticatory organ, it must not be forgotten that in young birds are often to be found tubercles on the bills, having

beneath them gelatinous, vascular, nervous pulps, like those of mammalian teeth. In the sensitive nature of the end of some beaks is noticeable a fusion of the function of prehension with that of tactile sensibility. B. Deglutition.—The tongue is a very imperfect organ, of little use in the performance of this action, of little use as an organ of special sense. There is no uvula; there is no epiglottis. Clearly, there are few muscles to perform the first or voluntary stage of swallowing. This first stage is mainly accomplished by a jerk of the head, to which the length of the neck helps to give force. With food as yet unmasticated, a wide and dilatable œsophagus is necessary. Some birds, as the Toucan, have the power of regurgitating their food from the stomach and submitting it to a rude kind of mastication by the beak ere they re-swallow it. This action is curiously suggestive of the 'rumination' of certain *Mammalia.* C. Stomachs.—The fact that it is necessary to use the plural number here is indicative of a lower organization than is to be met with in *Mammalia.* The stomachs of birds are three:—(a) The Crop.—A lateral dilatation of the œsophagus, whose office is to retain the rapidly-ingested stores of food until they can be passed on into the interior of the alimentary canal for digestion. The crop of *Aves* is as the storehouse of the squirrel or dormouse, the larder of the man. Pigeons have two crops, one on each side, and during the breeding season the mucous membrane of these organs secretes a milky grey fluid, that is poured out in large quantity and mixed with the contained grains. Whether this secretion is in itself nutritive or acts as a digestive fluid on the grains, it is of use to the young, and calls to mind the special provision met with in *Mammalia* for nourishing the offspring. (b) The Proventriculus.—In *Reptilia* there is but one stomach, and the portion of that nearer the œsophagus is the true digestive region, whilst the lower end partakes of the nature of a gizzard. In *Aves*, the two regions of reptiles become distinct stomachs. The former of them is represented by the proventriculus. This organ, with its follicles, each provided with many gastric tubuli at right angles to its length, is the true digestive stomach. (c) The Gizzard. — Once more we have the function of mastication performed low down in the alimentary canal and not at the commencement thereof. Here is an enormously muscular stomach with huge tendinous plates and a cavity reduced to exceedingly small dimensions. Here are stones that have been swallowed with the food, now serving to crush that food under the strong contractions of these powerful muscles. Here, in short, is the mill whereto the proventriculus is the hopper. This third dilatation of the alimentary canal gives off the small intestine, which takes origin from the upper region of the gizzard, close to the point where the œsophagus enters that organ. This origin of the intestine from the upper part of the gizzard possibly prevents the stones often swallowed with the food from passing too readily out of the gizzard, where they are of use; into the intestine, where they are useless. D. Chylification—takes place in the small intestine. This presents no region fairly meriting the name of jejunum. It is short and nearly straight. As so many stones are taken into the mouth with the food, this short, straight alimentary canal is of use to the bird in the speedy getting rid of such stones as do escape from the gizzard despite the position of the point of origin of the intestine therefrom. Here, as in the larval and adult stages of the *Amphibia*, we find the vegetable feeders with relatively longer intestinal tubes than the animal feeders possess. Villi are well marked, but many zigzag folds are still present as remnants of a coarser method of increasing the absorptive surface. Many birds have a diverticulum, at times an inch long, showing where the yolk-bag communicated with the gastric cavity of the embryo. In the Apteryx this dilates into a sac lined with a yellow layer of yolk-remains. It is impossible to exclude from the account of chyle-making in birds the cæca, or blind tubes, that are said to mark the junction of the small with the large intestine. They are usually two, and, nominally at least, should correspond with the cæcum of *Mammalia*, and belong to the large intestine. Their office seems to be to prolong the digestive process, so as to atone for the rapidity that would be attendant on the shortness and straightness of the intestine. E. Defœcation.—The very short large intestine only consists of the rectum, unless the cæca be regarded as parts thereof. It ends in a cloaca, which receives the urinary secretion and genital products. F. Glands.—(a) The salivary are present, but are not very well developed. The food, however, is only a very short time in the mouth. (b) Liver. Largest in the least active birds. This fact reminds us of its greater relative size in the slow MOLLUSCA as compared with the active ANNULOSA. There is a gall-bladder, but the hepatic duct in birds passes directly to the gall-bladder, and there is no regurgitation from a duct leading from the liver to the intestine, as there is in man. (c) The Pancreas is large. Possibly this is due to the fact that this gland, which in

Mammalia helps the salivary glands in the conversion of starch into sugar, has in *Aves* to do nearly the whole of this important work, as the salivary glands are small. The gland is firmer than that of reptiles. It has more than one duct,—a sign of comparative lowness of organization,—and these ducts open into the intestine separately from the hepatic duct.

(2) *Mammalia.*—A. Prehension.—Only concerning ourselves with such prehensile parts as are met with at the beginning of the alimentary canal, we must notice the fleshy lips so peculiar to this class, and the many and varying arrangements for retaining food that has been ingested in too large quantities to be at once swallowed. These receptacles or pouches for food, whilst reminding us of the bird's crop, are, however, usually in connection with the mouth. The remarkable Ornithorhynchus or Duck-billed Platypus, lowest of Mammals, has a beak. B. Mastication.—The complexity met with in the arrangement of the teeth in *Mammalia* has led to the use of their dental systems as a means of classifying the orders. (a) Number. Scarcely any are without teeth. Ant-eaters have none. Cetacea have teeth in the embryonic condition, and baleen or 'whalebone' afterwards. The typical number of teeth in this class is 44; the average 32, the number man possesses. The largest numbers (a sign of low organization) are met with in the water Mammals, and the teeth in these animals are, moreover, very simple in shape and structure. (b) Duration. There are never any second teeth in the Cetacea or whale order. The sloth has its first set persistent. The majority of Mammals, however, have two sets of teeth, one deciduous and one permanent. (c) Insertion. The teeth

are never ankylosed to the supporting bones, but have distinct sockets. (d) Structure. For the first time incisors, canines, molars, are quite distinctively marked off from each other. Further, each individual tooth presents a distinct crown, neck, and fang. More than one fang belonging to a given tooth is also peculiar to this highest class of VERTEBRATA. (e) Homologies. The teeth of Mammalia are structurally of similar nature to the antlers of deer. The most interesting homology to us, however, is that with the jaws of Invertebrata pointed out in a former chapter. (g) Adaptation. The adaptation of the dental apparatus to the kinds of food affected by different animals is another instance of advanced specialization. C. Deglutition.—The swallowing of the food is now accomplished by the contraction of a number of special muscles, voluntary and involuntary. D. Insalivation.—The Cetacea, aquatic *Mammalia,* have no salivary glands at all. The seal, an aquatic Carnivore, has a rudimentary parotid gland. In the remaining orders every stage is met with, from simple follicles to a set of highly complex glands. It is quite possible that individual glands may discharge special functions to a certain extent, and that there is even a subdivision of the apparently simple act of insalivation, for the parotid gland is largest in Mammals whose food requires prolonged mastication, and the submaxillary in those needing a viscid, lubricating secretion. E. Chymification.—A true abdominal cavity shut off from the thorax by a transverse muscle, the diaphragm, appears in this class only. The peritoneum, or serous membrane, enveloping and supporting the organs contained in the abdomen, is of very great complexity. The stomach or chymemaking organ is very distinctly marked, and in no case acts as a masticating agent, but only as a true digestive cavity. The Ornithorhynchus has the two openings of the œsophagus into and of the intestine from the stomach close to each other, as in *Aves*. In the majority of *Mammalia* they are at opposite ends of the stomach. The fourfold stomach of ruminating animals seems to be an instance rather of retrogression than advancement in the progress from general to special. F. Chylification by the aid of the intestinal secretion, the bile, and the pancreatic fluid. (a) Intestinal fluid. Secreted by glands in the walls of an intestine whose regions are very clearly distinguishable one from the other. Villi are present in large numbers, except in the Ornithorhynchus. (b) Bile. Secreted by a liver whose lobes are more distinct from each other than in the hepatic organs of lower classes. The liver is larger in the flesh-eating animals than in the herbivorous. Its various shapes depend upon the number and arrangement of the other viscera amongst which it has to be placed, and have relation to the movements of the animal. (c) Pancreatic fluid. Secreted by the pancreas, which is firmer than in *Aves*, and larger. Its greater size is due to the increase of the splenic or left end of the gland. That portion is in birds rudimentary. G. Defœcation.—With the exception of the Ornithorhynchus and its ally, the Echidna, the alimentary canal terminates by a special opening, through which no urinary or reproductive products pass. At last, therefore, the digestive tract is entirely shut off from every other, with the exception of the very lowest *Mammalia*, who, in the retention of the cloaca, as in so many other points, show their affinity to the class *Aves*.

CHAPTER V.

ON ABSORPTION IN THE INVERTEBRATA.

THE fate of food that is digested is to become tissue. Digested food is brought into close relationship with the various tissues in four ways:—A. Immediately: the food in the very process of digestion is brought into actual contact with the tissues that are to be restored by it. Here there is a fusion of the two functions of digestion and absorption. B. Digested food transudes through the walls of the alimentary canal into the body cavity, and is taken up by the walls of, and the organs suspended in, that cavity. C. The digested food is taken up from the alimentary canal by the blood-vessels distributed on the walls thereof. Through the medium of the vessels the products of digestion are carried to all parts, all tissues of the body. Here is a fusion of the functions of absorption and circulation. D. A special set of vessels is met with in the walls of the alimentary canal, distinct from those carrying blood. These vessels take up the digested food, and ultimately pour it into the blood system. The blood-vessels in their turn convey the materials thus supplied to them to the tissues. In this case absorption, structurally and functionally, is distinct from digestion and from circulation.

In the cases under A, the digested food at once becomes tissue. In those under B, it passes through a transitory condition, wherein it is known as chylaqueous fluid. This fluid is at no time enclosed in any definite vessels. In the cases under C, the results of digestion become incorporated with the blood ere they reach the tissues for which they are destined. In the cases under D, the contents of the absorbent vessels are known as chyle, and, though of a nature somewhat similar to that of blood, are distinct from that fluid. In due time the blood becomes tissue. It is this function of absorption, at first not distinct from that of digestion, then united with that of circulation, finally performed by distinct organs, that is now to be considered.

A. PROTOZOA.—(1) *Gregarinida.*—These creatures, immersed throughout their existence in the tissues or in the chyle of higher animals, absorb by the whole of their surface fluids that can probably be converted into the extremely elementary structures of the Gregarines without undergoing further change. Perhaps no other animals present such a complete want of differentiation between the functions of digestion and absorption.

(2) *Rhizopoda.* — It will be remembered that the simple forms of Rhizopoda, such as Amœba, take in food at any point in their body, but only at one region of the body at one given time. The whole surface can ingest food: only one portion of it ingests at a time. The food particles make their way slowly through the sarcode, growing smaller and smaller as they pass along. The sarcode through which they are passing absorbs nutrient matters from the food particles. There is no defined channel through which these food matters pass, though it has

sometimes occurred to the writer, that even in this sarcodic mass there may be lines of least resistance, and it may be possible that the food particles make their way through the sarcod in directions more specialized than at first sight might be imagined.

In the Compound *Rhizopoda* only certain regions of the complex sarcodic body take in food. The food so ingested passes through more or less of a Compound Rhizopod in a similar fashion to that met with in the simple forms.

(3) *Infusoria.*—The food, which may possibly undergo some digestion in the short œsophagus, after entering the sarcode, is formed into food vacuoles, that pass round the body in a definite line just below the cuticular layer. Only the sarcode immediately in contact with the food vacuoles as they pass round can be regarded as truly absorptive. Here is, then, the first marking off of a region (only a region) of sarcode whose work is that of absorbing nutrient materials from the food, and transferring them to other parts of the sarcodic body.

CŒLENTERATA.—(1) *Spongida.*—In this class, where the food is introduced in the water that is constantly flowing through the sponge, the sarcodic masses lining the interior present no more marked distinction between the processes of digestion and absorption than do the *Rhizopoda.*

(2) *Hydrozoa* rank, as far as absorption is concerned, under division A. The digestive cavity and somatic or body cavity are one. The food, when it has undergone digestion, is absorbed by the walls of the cavity, and is converted into the issues met with in those walls. As far as the function of absorption is concerned, the great advance here, as contrasted with Infusoria, is that the absorption is effected not by sarcode, but by endoderm, a mem-

brane differentiated into matrix and cells. Just as in *Infusoria* the sarcode immediately in contact with the circulating food vacuoles was the true absorbent part, and transferred absorbed materials to the surrounding sarcode, so may the endoderm be regarded as the true absorptive layer transferring absorbed materials to the ectoderm upon its exterior. This class, *Hydrozoa*, leads us by a natural gradation into division B; for though the food in the very process of digestion is brought into actual contact with at least some of the tissues that are to be restored by it, yet the somatic and digestive cavity contains a chylaqueous fluid.

B. (3) *Actinozoa.*—This, the highest of the three classes met with in the CŒLENTERATA, ranks, as far as absorption is concerned, under division B. The digestive cavity is distinct from and is suspended in the somatic cavity. The digested food transudes through the walls of the digestive cavity, or passes directly through its inferior aperture into the general cavity of the body. Arrived therein, the endodermic lining of the outer wall of that cavity, and of the mesenteries, absorbs the nutritious matters. In this case digestion and absorption are differentiated from each other, but the absorption is still very general. The somatic cavity in *Actinozoa* contains a chylaqueous fluid—that is, a fluid consisting largely of water, yet partially organized. It presents albuminoid spherules, which may be looked upon, perhaps, as the precursors of the white corpuscles of chyle and of blood in the higher animals.

ANNULOSA.—(1) *Scolecida.*—This aberrant class, mainly entozoic, in this function as in so many others, shows reversion to a simpler type. Immersed for the most part in the chyle or the tissues of higher animals, they absorb food by the whole of the external surface, and present a blending of absorption and digestion akin to that in the entozoic *Gregarinida*. The *Echinodermata* and *Annelida* of the sub-kingdom ANNULOSA, using that term in its widest sense, and the *Polyzoa*, *Ascidioida*, and *Brachiopoda* of the sub-kingdom MOLLUSCA, all range under the same head as the *Actinozoa* in respect to absorption. In all these classes there is an alimentary canal suspended in a body cavity, and in most cases entirely shut off therefrom. In all these classes the digested food transudes through the walls of the alimentary canal into the body cavity, and is taken up by the walls of, and the organs suspended in, that cavity. The process of absorption is distinct from that of digestion, but is not performed thus far by any special organs.

C. In the remaining classes of Invertebrata—namely, *Arachnida*, *Myriapoda*, *Insecta*, *Crustacea*, of the sub-kingdom ANNULOSA, and *Lamellibranchiata*, *Gasteropoda*, *Pteropoda*, and *Cephalopoda*, of the sub-kingdom MOLLUSCA—there are distributed on the walls of the alimentary canal blood-vessels. There may be still some transudation directly through the walls into the body cavity in some of the lowest of these classes, but probably the main work of absorbing the digested food is performed by the blood-vessels, more especially, perhaps, those carrying venous blood. For the first time the digested food is taken up by vessels. This is, of course, a decided advance on anything that has been seen hitherto; but it will be observed that the vessels that absorb are not vessels specially set apart for the purpose of absorbing: they are performing the ordinary function of veins, and are carrying away from the tissues of the alimentary canal the effete products resulting from the work of those tissues. But in addition to this is laid upon them the office of receiving the fresh material introduced into the system through the alimentary canal. These vessels are not only transmitting blood, but are absorbing chyle; there is a fusion of the functions of absorption and circulation.

CHAPTER VI.

ON ABSORPTION IN THE VERTEBRATA.

D. In the sub-kingdom Vertebrata alone does there exist an absorbent system distinct from either the digestive or the circulatory—that is, a set of organs whose sole functions are the absorption of matter that can be converted into tissue, and the conveyance of such histogenetic material to the blood system. There are two sources of this matter that is fit for conversion into tissue:—(*a*) Digested food. The set of vessels concerned in the absorption of food materials are the lacteals, and the fluid they contain is chyle. (*b*) The unused plasma that has transuded through the walls of the capillaries. Blood going to a quiescent muscle, or to any organ that is for the time not in active use, passes through the thin walls of the capillaries in quantities larger than those actually required by the resting structure. Only a part of the transuded plasma is used; the excess is absorbed by certain vessels, and restored by them to the blood system. These absorbing vessels are lymphatics, and the fluid they contain is lymph. Throughout the body of Vertebrata there is a tissue, covering, lining, and connecting organs, and entering into the very structure of almost every part. It is the well-known connective tissue. Amidst the irregular plates of this tissue are interspaces or lacunæ communicating with each other, and containing fluid of a serous nature. This fluid is the result of transudation from the blood-vessels. It is taken up again and restored to the blood-vessels by the lymphatics. The origin of the lymphatics must therefore be sought for in connection with the cavities, *large or small*, met with in connective tissue. Whilst, therefore, the deep origins of many lymphatics are in the small interspaces of connective tissue, some are found to commence by small openings about twice the size of a large blood corpuscle in the large serous cavities of the pleura, pericardium, and other serous membranes. These serous cavities are probably to be regarded as gigantic lymph spaces. In this chapter and its successor, an attempt will be made to trace the gradual increase of complexity in this absorbent system, from its first appearance in Pisces to its highest development in Mammalia.

(1) *Pisces.*—(*a*) Lacteals, or absorbents from the alimentary canal.—The internal surface of the intestines of Pisces is in most cases smooth. There are no villi or internal projections increasing the absorbing surface. The lacteals, therefore, commence as a network on the outer side of the most internal or mucous coat of the intestine. From this network issue vessels. These course along beneath the serous external covering of the intestine to the large reticulate receptacles that extend very indefinitely over a considerable area of the alimentary canal. These chyle receptacles join with the lymph system to form ultimately on each side of the body a short, broad trunk, common to both absorbent systems, and entering the jugular vein of the blood system. The chyle of this class is clear

and colourless as the lymph. It contains none of the organized structures that in Mammalia are the precursors of the white blood corpuscles. (*b*) Lymphatics or absorbents from the body generally.—These are numerous, and present many plexuses or networks, and sinuses or enlargements. Ultimately the lymphatics join with the lacteals in the common canal on each side referred to above. These two canals may be called the thoracic ducts, as they are homologous with the single thoracic duct in man.

The vessels of the absorbent system of Pisces present only one coat, not three, as in the higher Vertebrata. That coat is of connective tissue. The very large trunks present, in addition to this, an exceedingly delicate epithelium coat. Pisces, except where the large trunks enter the venous system, have nothing to represent the valves that serve in the higher Vertebrata to determine the course of the fluids moving in the vessels of the absorbent system. There are no lymphatic glands, though certain accumulations of indefinite tissue in the walls of some of the sinuses, and perhaps the plexuses of lymphatics, foreshadow the lymphatic glands of more advanced classes. The lymph corpuscles are very few in number. The points of union between the two great systems of vessels, the circulatory and absorptive, are much more numerous in this lowest Vertebrate class than in the others. The lymphatics open into veins at several places other than where the terminal ducts enter the venous system. Thus the work done in the higher Vertebrata by the absorbent vessels is now done by a set of vessels not so completely distinct from those carrying blood as are their homologues in Mammalia.

Certain vascular glands that are regarded as belonging to the absorbent system are met with in Pisces and in all Vertebrata. They are not to be confused with the mesenteric and lymphatic glands encountered in the very course of the lacteals and lymphatics of the higher Vertebrata. The *spleen* is present in all Vertebrata save the very lowest fishes. The *thymus* 'developed in relation to the primitive aortic arches' is present in all save Amphioxus, the lowest fish. The *thyroid gland*, found near the arch of the aortic, and the *supra-renal* capsules, in close relation to the kidneys, are said to occur in Pisces, and are certainly to be found in the upper classes of this sub-kingdom.

(2) *Amphibia.*—(*a*) There are no villi. The lacteals begin as a coarse plexus in the walls of the alimentary canal. Vessels running therefrom accompany the mesenteric arteries, forming generally a continuous netted sheath around the artery. They open into a receptacle, which is large in the frog, but contracted and assuming the form of a thoracic duct in the newt. This receptacle is reflected about the aorta, divides anteriorly, and its branches end in the subclavian veins. Two thoracic ducts, therefore, may be said to exist in this class. (*b*) Many lymphatic vessels are found in the trunk and in the limbs, forming sheaths round the blood-vessels. This close relationship, as far as distribution is concerned, between the vessels of the two systems is not insignificant; but the chief supply of the lymph of Amphibia is derived from the large lymph spaces between the skin and the muscles, and in the intermuscular spaces in the limbs. Here the connection between the absorbent system and the lacunæ of connective tissue is most plainly visible. The Amphibia possess two pairs of lymphatic hearts, thin-walled,

transparent, contractile, subcutaneous expansions. The anterior pair lie close to the transverse processes of the third cervical vertebra, and are in connection with the jugular veins. The posterior pair are close to the hip joint, and generally communicate with the sciatic veins. Their contractions, due to striated muscular fibre, are not synchronous, nor are they synchronous with those of the heart nor with the movements of respiration. In this class the coats of the vessels are not very complex; there are no valves, save where the lymphatics join the veins; there are no better-defined lymphatic or lacteal glands in the direct course of the vessels than in Pisces, and the corpuscles are but few. The communications of the absorbent system with the circulatory are still numerous.

(3) *Reptilia.*—(*a*) In the Ophidia or snakes the lacteals begin in a very close network between the muscular and mucous coats of the intestine. For the first time villi or internal projections of the mucous coat of the intestine are met with. The lacteals end in a large receptacle. This receptacle partly envelops the aorta, and gives off first the right or inferior duct, and then a left or superior duct. These two unite by many and various branches, and both end in a plexus near the heart, whence two or three terminal trunks carry the fluid to the two great precaval veins. There are here two thoracic ducts. This description is in the main true of the Lacertilia or lizards, and of the Chelonia or turtles and tortoises. In the Crocodilia or crocodile order the absorbent system shows signs of advance. The chyle is white, the receptacle more condensed and defined, the offshoots from it more like vessels than 'plexiform conduits,' and

there is a true gland developed in the mesentery. (*b*) The lymphatics present many irregular plexuses and dilatations. They end in the receptacles, or in the ducts, or in the plexus near the heart. All the orders of Reptilia have one pair of contractile lymph hearts corresponding with the posterior pair of the Amphibia. Two coats can now be distinguished in the vessels and in the lymph hearts, but they are very thin. The valves are not very numerous, and when present are imperfect. They are, however, sufficiently evident at the points of union of the absorbent and venous systems. The glands are only represented by the solitary one in Crocodilia. The corpuscles in the absorbent fluids are much increased in number, and finally the number of points where the blood-vessels and lymphatics join is reduced, though it is still greater than the number observable in Mammalia.

(4) *Aves.*—A. Lymphatics.—(*a*) Distribution.—A general advance of complexity in distribution is perceptible, but there are still two thoracic ducts. (*b*) Structure.—The three coats are still better marked off structurally from each other.

B. Lacteals. — The number of lacteals is very considerably increased in this class.

C. Glands.—Lymphatic glands are only met with in the neck and upper part of the thorax. There are no lacteal glands.

D. Lymphatic Hearts.—The goose, swan, and a few other birds have two dilatations in the course of the lymphatic system, whose walls are of striated muscular fibre. The dilatations, however, do not contract. They have the structure of lymphatic hearts, therefore, without the function. Physiological change has preceded anatomical once more.

CHAPTER VII.

ON ABSORPTION IN THE VERTEBRATA.

Mammalia.

IN the sub-kingdom Vertebrata alone is there an absorbent system distinct from the digestive and circulatory. In the Mammalia, the highest of the classes of that sub-kingdom, this system acquires its most complex form. In this paper the absorbent system of Mammalia will be considered under the following heads:—A. *The Lymphatics.* B. *The Lacteals.* C. *Glands.* D. *Lymphatic Hearts.*

A. The Lymphatics, or vessels concerned in absorbing from the body generally.—An account of these vessels involves a history of their distribution, their structure, their functions.

(*a*) Distribution of the Lymphatics.—This has been most completely traced out in man. The lymphatics are nearly universal. Scarcely a part, scarcely a tissue, of the body is without them. They begin, as was enunciated in a preceding chapter, in the areolæ or interspaces of connective tissue; some superficially, as the subcutaneous and subserous lymphatics, others deeply in the very substance of organs. The lymphatics generally follow the course of the veins. Thus the superficial ones of the lower limbs are in close relation to the saphenous vein, and, after joining the deeper vessels and again dividing ere they traverse the inguinal glands, they are in close relation to the iliac veins. These lymphatics of the lower part of the body end in the *receptaculum chyli*, a considerable dilatation placed at the root of the mesentery. In some of the lowest Mammalia this receptacle is still a network, not a single cavity. From it arises the main duct of the absorbent system, the thoracic duct. Normally single in this highest class of the kingdom Animalia, the thoracic duct is double in the lowest members of the class, and even in some Carnivora. In animals where the duct begins as a single one, it may bifurcate during its course upwards through the thorax. Piercing the diaphragm (or muscular partition between the abdomen and the thorax that is special to the class Mammalia), the duct runs upwards behind the œsophagus as far as the seventh cervical vertebra; then, after curving over the subclavian artery, it enters the blood system at the point where the left subclavian vein and the left internal jugular vein join. The orifice of entry is guarded by semi-lunar valves. In some of the Ungulata the duct enters the azygos vein. As the thoracic duct ascends, the lymphatics of the regions of the body above the lower limbs join it, with the exception of those from the right upper half of the trunk, from the right arm and right side of the head and neck, from the right lung and right side of the heart. These pour their contents into a duct as broad as the thoracic, but only about 12 mm. in length, entering the blood system on the right side of the body at a point similar in position to that whereat the principal duct enters the blood system on the left side of the body.

In some Mammalia, and even in exceptional cases in the highest of Mammals, the two ducts are transposed, and the chief one is on the right, the smaller one on the left, side of the body.

It has not been demonstrated that the mammalian absorbent system communicates with the vascular save at the two points mentioned above.

(*b*) Structure of the Lymphatics.—Not only are the lymphatics of Mammalia far more numerous and more minutely distributed than those of Aves and the lower vertebrate classes; they are of a far higher order of structure. Their walls are stronger, and in the majority of them the following coats present themselves:—(α) Internal, of flat nucleated epithelium cells, and a basement membrane. (β) Middle, of circularly-disposed non-striated muscle fibre. (γ) External, of connective tissue, the fibres arranged for the most part longitudinally. In the thoracic duct, the external coat has moreover longitudinal non-striated muscular fibres. Again, the valves, which in the lower classes are either absent or very few in number, are here numerous and efficient. For the most part, these semi-lunar folds of the internal coat are in pairs.

(*c*) Functions of the Lymphatics.—These were spoken of at length in a former chapter. Briefly, they take up such fluids as may be exuded into the interspaces of the connective tissue whence they take origin.

B. The Lacteals, or vessels concerned in absorbing the digested food from the alimentary canal.—An account of these vessels involves a history of their distribution, their structure, their functions.

(*a*) Distribution of Lacteals.—In the lower classes of the sub-kingdom Vertebrata, the interior of the alimentary canal is smooth, and the absorbent vessels commence as a simple network. In the Mammalia the internal coat of the alimentary canal is no longer smooth, but its surface is increased by its extension into minute prominences, projecting into the interior of the alimentary canal. These are the intestinal villi. In the external depressions caused by the extension of the internal coat into these villi, the lacteals commence either as single canals or as networks. Of course, either canal or network is closed, and the digested food has to pass not into an open-mouthed vessel, but through the membrane of a closed one. Numberless lacteals from numberless villi join to form a network representative of the commencing network in the lower vertebrate classes. From this network, which is confined to the connective tissue portion of the internal coat, branches proceed, perforating the middle and outer coat. These are joined by the ordinary lymphatics of the serous coat, and by the lacteals and lymphatics from the large intestine; and all these vessels empty themselves into the *receptaculum chyli*, whence proceeds the thoracic duct.

(*b*) The Structure of the Lacteals is the same as that of the lymphatics, but there are no valves. The lymphatics, like the veins, are distributed largely amongst muscles that are constantly con tracting. In the lymphatics, valves are of use in determining the direction of the movement of the contained fluid under pressure. The lacteals, distributed amongst comparatively quiescent internal organs, have no valves.

(*c*) The Functions of the Lacteals.—It must not be forgotten that the lacteals are specially modified lymphatics. Functionally they are lymphatics during the period in which digestion is not taking place. During that period the lacteals contain a clear lymph fluid; but their special office is the absorption of the products of digestion. Not the direct absorption: this is effected by the epithelial cells of the internal coat of the intestine generally, and by those on the villi specially. Each epithelial cell in the process of absorption fills gradually with an oil-like globule of fluid. This globule becomes reduced to a granular condition. The surrounding cell wall disappears. The granules pass through the basement membrane, through the space intervening between that membrane and the commencing lacteal, through the delicate wall of the lacteal into the cavity thereof. This passage through consecutive membranes is possibly of importance. It is perhaps not going too far to say no fluid passes through a living membrane without change being wrought upon that fluid.

C. Absorbent Glands.—Here I may be permitted to remark that the name gland is a somewhat unfortunate one. The word should be confined to those structures that secrete or separate something from the blood. It would perhaps be advisable in the present case to return to the name Professor Owen uses, 'Absorbent Ganglia.' An account of these ganglions involves a history of their distribution, their structure, their functions.

(*a*) Distribution of the Absorbent Ganglions.—These organs are far more numerous in mammals than in any other vertebrate class. (α) In the trunk, lymphatic glands occur in the thorax, at the anterior and posterior mediastina, and at the roots of the lungs; also in the abdomen near the spleen and near the principal blood-vessels. (β) In the extremities they are situated close to the joints. (γ) In the head and neck they are found external to the cranial cavity. (δ) The lacteal glands are situated in the mesentery, and are especially numerous in the Ungulata (or hoofed mammals) and Primates (apes and man). In the Carnivora (flesh-eating animals), the lacteal glands are condensed into one mass, called by the old anatomists 'Pancreas Asellii.'

(*b*) Structure of the Absorbent Ganglions.—These are of too complex a nature to be treated of exhaustively in this volume. Generally, a ganglion presents a capsule of connective tissue. Internally to this the organ presents a series of spaces partially separated one from the other by incomplete partitions of connective tissue, and partially filled by a white 'gland pulp.' Structurally, the ganglion is a dense network of absorbent vessels. The fluid brought by afferent vessels passes through the gland, either soaking through the 'gland pulp' or traversing the spaces between the partitions and that pulp, and quits the ganglion by efferent vessels. The distinction between the cortical or outer and medullary or inner portion depends mainly upon the more complete division of the vessels, and upon the small amount of fibrous tissue in the internal or medullary portion.

(*c*) Functions of the Absorbent Ganglions.—The absorbed fluids are delayed in passing through these ganglions. The 'gland pulp' is rich in corpuscles. The efferent vessels contain more corpuscles than the afferent. Hence it is inferred that these ganglions are the seats of the manufacture of lymph corpuscles, which are identical with the white of the blood. Probably the ductless vascular glands, not met with in the direct course of the absorbent vessels, such as the spleen and the suprarenal capsules, are of a similar nature.

D. Lymphatic Hearts.—In the lower classes of the Vertebrata, at certain points in the absorbent system contractile expansions are met with, called lymphatic hearts. No such rhythmically-pulsating sacs have been seen in Mammalia, but in the ox the *receptaculum chyli* and the lacteals at certain points have been observed to contract and dilate.

CHAPTER VIII.

CIRCULATION.

The Blood in Invertebrata.

FOOD is converted by the process of digestion, or by the processes of digestion and absorption, into a nutritive fluid—the blood. The blood is carried to the different organs of the body to supply the waste of their tissues. This movement of the blood is its Circulation. In the present chapter and its successor will be considered the nature of the blood itself; in succeeding chapters, the circulation thereof in different animals.

A. *The Blood.*—Generally, two facts may be predicated of the fluid known as blood. A physiological fact: blood is nutritive; it contains materials for the restoration of the used tissues. An anatomical fact: blood is corpusculated. Floating in the fluid or plasma are certain minute solid particles, varying in number, varying in nature in different animals. These are the blood corpuscles.

The physiological fact is recorded first. It is often possible to notice certain tissues or organs performing functions before the particular structure usually associated with that function is observable. It is possible that, in evolution, physiological change generally precedes anatomical. At least, in the special instance now under discussion, a fluid is met with in the lower animals that is not corpusculated, but is probably nutritive.

Animals without Blood.—In the PROTOZOA no part of the sarcode is transformed into aught that can be regarded as blood. The sarcodic matter lining the canals traversing the skeleton of *Porifera* or sponges is also destitute of any fluid that can be spoken of as nutritive.

Animals with Non-corpusculated Blood.—In some of the *Scolecida* or entozoic worms the nutritive fluid found in those interstices of the mesoderm that represent the somatic cavity of other animals is said to be free from corpuscles. Notably the Nematoidea or thread-worms present this simplest form of blood. These *Scolecida* constitute the lowest class of animals approaching towards or attaining an annulose structure. In the lowest class, moreover, of the MOLLUSCA (using that term in the widest significance), viz. the *Polyzoa*, the fluid contained in the somatic or perivisceral cavity is very watery, and has but few, if any, corpuscles. This fluid, derived from the food that has been digested in the alimentary canal and has transuded through the walls of that canal, is clearly nutritive; it is the 'chylaqueous fluid' of some writers. This name brings out strongly two chief points in relation to the fluid—viz., its histogenetic or tissue-forming nature, and the large quantity of water entering into its composition. Again, the HYDROZOA, the lower of the two classes in the subkingdom Cœlenterata that are provided with blood, have in the cavity that is at once gastric and somatic a very watery, non-coagulable fluid, almost destitute of corpuscles. That the chylaqueous fluid is blood-like is demonstrated by the fact that the fluid of the body cavity of *Annelida* yields on investigation not only albumin and fibrin, but crystals which are derived from the water that constitutes so large a part of the nutritive fluid. Finally, the young of many Invertebrata have blood without corpuscles. Once again we see that development is a progress from the general to the special, from the lower to the higher form, and that the earlier stages of the history of higher animals are similar to the adult forms of lower ones.

With Corpusculated Blood. — The non-coagulating chylaqueous fluid in the gastric and somatic cavities of *Actinozoa* contains corpuscles; but few, if any of them, are distinct cells with wall and nucleus. In the *Echinodermata* the nutritive fluid of the somatic cavity contains solid floating corpuscles, but without wall and nucleus. In both these cases, the corpuscles are therefore of an exceedingly rudimentary nature. They are probably small masses of matter with no definite limiting membrane on their exterior, akin, perhaps, to the albuminous molecules in our chyle. In the *Myriapoda*, three distinct forms of blood corpuscle are seen. It should be observed that the blood of this class is contained during some part of its course in actual vessels, and is not always lying freely in the general cavity of the body. Yet, even in Myriapoda, no cell wall is observable in the blood corpuscles. The simplest kind are pellucid central nuclei invested by a few granules. Next rank the oat-shaped corpuscles, where the nucleus is still very evident. The third and most perfect form presents a central nucleus, surrounded and almost obscured by a large number of granules. As yet no definite cell wall is to be seen on the exterior of these granules.

The nutritive fluid of *Annelida* is coagulable, and contains oval, flat, granular structures, with no limiting membrane, as well as actual cell corpuscles of a fusiform shape and devoid of granules. Here, then, are some corpuscles with a true wall, but all the solid, floating particles of the blood are not yet of that high order of structure.

The lower MOLLUSCA, *Lamellibranchiata* and *Gasteropoda*, have corpuscles whose nuclei, though generally present, are sometimes very indistinct. In the higher MOLLUSCA, and in the *Arachnida*, *Crustacea*, and *Insecta*, the blood corpuscles are very well marked. They are oval in shape, granular, and present a very distinct wall externally and nucleus within.

All these bodies met with in invertebrate blood are colourless. They contain no hæmoglobin, and represent therefore the white corpuscles of vertebrate blood, and the lymph and chyle corpuscles of the absorbent system in Vertebrata. Whilst this is true, it must not be forgotten that in the *Annelida* the fluid contained in the respiratory or pseud-hæmal set of vessels does contain a substance allied to hæmoglobin or the colour-matter of the red corpuscles in man. This pseud-hæmal fluid, to be discussed more fully in the survey of respiration, may perhaps be spoken of as a fluid representing a fusion of the two usually distinct functions of circulation and respiration, or, to use the expressive term of Professor Huxley, as a 'respiratory blood,' though it is questionable if the fluid is nutritive. In other cases where the blood appears to be coloured, the colour is due to substances in the plasma or liquid portion, not to anything in the corpuscles. Thus the blood of Insecta is, though usually without colour, sometimes of a green or yellowish or even rarely of a red hue. But that colour is not due to the flat, oat-shaped, granular corpuscles with their well-defined walls and nuclei. It is due to the liquid wherein they float.

But in *Gephyrea*, the class of marine worm-like animals closely allied to the *Annelida* and represented by Sipunculus, the blood corpuscles are said to contain between the external wall and the central nucleus a coloured fluid. Here is possibly the first appearance of a coloured corpuscle; but it should be carefully noted that the colour is not distributed in the corpuscle in the same way as it is in the mammalian corpuscles.

Surveying the Invertebrata as a whole, we find, first, animals, as PROTOZOA, with no blood at all; next, animals, as some *Scolecida*, with blood containing no solid particles; then such creatures as *Echinodermata*, where solid pieces of protoplasm not surrounded by a wall are met with; the *Myriapoda*, where a central nucleus is enveloped by granules, but an external wall is yet wanting; *Crustacea*, whose granular corpuscles have wall and nucleus, but are colourless; *Gephyrea*, with limiting membrane, nucleus, and coloured contents. To contrast these various conditions of the blood corpuscles of Invertebrata with the stages in the development of our own red corpuscles is not without interest. There is a time in the history of the highest mammal when there is no blood developed; there is a time when only fluid blood destitute of corpuscles is to be seen; possibly our blood corpuscles commence as minute fragments of protoplasm derived from the digested food: these minute granules may coalesce in the absorbent vessels and form free nuclei; the nuclei may become surrounded by granules, a wall be developed on the exterior of these, and a white corpuscle would result. The history of the transformation of this colourless corpuscle into the red falls under the account of the nature of the blood in the classes of the sub-kingdom VERTEBRATA.

CHAPTER IX.

CIRCULATION.

The Blood in Vertebrata.

THE nature of the blood or nutritive fluid in the sub-kingdom Vertebrata will be considered in the present chapter. It will be necessary (*a*) to distinguish between cold-blooded and warm-blooded vertebrates. (*b*) To speak of the quality of the blood met with in the different members of the group. (*c*) Of the composition of that fluid. (*d*) Of the white corpuscles. (*e*) Of the red.

(*a*) The Distinction between Cold-blooded and Warm-blooded Animals.—These terms are in frequent use even in ordinary converse. Like so many technical phrases that become part and parcel of the vocabulary of the many, they are but imperfectly understood. A cold-blooded animal is one the temperature of whose blood is dependent on the temperature of the medium wherein it lives. A warm-blooded animal is one the temperature of whose blood is independent of the temperature of the medium wherein it lives. *Pisces*, *Amphibia*, and *Reptilia* have no power of maintaining a body temperature that is fixed, and not dependent on that of the water or the air surrounding them. *Aves* and *Mammalia* have the power of maintaining a fixed body temperature, irrespective of the fluctuations to which the temperature of the air enveloping them may be subject. The temperature of a bird or of a mammal in health only ranges a very short distance on either side of a certain definite point, and the raising or lowering of that temperature, even to the extent of only two or three degrees, is a sure indication of disease.

These two classes, capable of keeping up a fixed blood temperature at the expense of certain of their tissues, mainly the adipose or fat tissue, are called warm-blooded. The three lower classes of Vertebrata without this fuel-supply of fat or other tissue are, as far as temperature is concerned, at the mercy of the element they inhabit. They are cold-blooded animals.

As life is the adjustment of internal conditions to the external, and as the warm-blooded animals have the power of adjusting their natural condition of blood temperature to the external condition of the temperature of the surrounding air in an active rather than in a passive way, they may be said to rank higher in the scale of living beings than the cold-blooded.

(*b*) The Quantity of Blood in the Different Classes of the Sub-kingdom Vertebrata.—The higher the class, the larger the quantity of blood in its individual members. There are certain exceptions, however, to this general principle. Thus the Tunny has more blood than any reptile possesses. Especially is the difference between the amount of the nutritive fluid in the cold and in the warm-blooded animals noticeable. The ratio of the weight of the blood to the weight of the body generally increases enormously in the two higher or warm-blooded classes as contrasted with the three lower, and that ratio is much larger in the mammals than in the class *Aves*. In *Reptilia* the average quantity of blood is from $\frac{1}{13}$ to $\frac{1}{17}$ of the weight of the whole body. In the warm-blooded VERTEBRATA the average quantity of the blood is, according to Vierordt, $\frac{1}{13}$ of the weight of the body. But with the increase in the quantity of blood there is, moreover, an advance in the quality. This brings us to

(*c*) Composition of Blood in the Vertebrata.—The lower classes present a larger percentage of water in their blood than the higher. The latter have a greater proportion of organic matter than the cold-blooded Vertebrata. The following table will demonstrate this fact:—

The Eel	presents in	1000 parts of blood,	60	of dried solids.
The Frog	,,	,,	69	,,
The Tortoise	,,	,,	80	,,
The Hen	,,	,,	157·1	,,
Man	,,	,,	209·5	,,

The proportion of the red corpuscles in blood is in direct relation to the normal temperature of the body, and to the amount of muscular and nervous work done by the animal. Contrasting mammalian blood with avian, the difference in composition is very marked, and is accompanied by a large increase in the number of the blood corpuscles. One of the most remarkable facts in this connection is the exceeding richness of organization of the blood of the serpent order, or the Ophidia. In the matter of solid constituents, this order ranks highest among the cold-blooded Vertebrata. This may be due to the fact that serpents seldom if ever drink; or, as my friend Mr. Edwin Richardson has suggested, may be associated with the enormous muscular power of the animals in this order, a muscular power whereof the commonest illustration is their capacity for raising their huge bulks upon a comparatively small basis of support, without the aid of ordinary limbs.

(*d*) The White Corpuscles.—(α) Their Number.—These are, as was stated in the preceding article, the only corpuscles met with in the blood of the invertebrate classes. The same statement is true of the lowest known members of the sub-kingdom we are now considering. The Amphioxus, of the order Pharyngobranchii of the class *Pisces*, has white blood corpuscles and no red. A fish of a much higher type, the Leptocephalus, belonging to the Teleostei, is said to possess the same peculiarity. But in all the rest of the VERTEBRATA, the red, which probably take origin from the white, preponderate, and, save within a short period of the ingestion of food, the white are in an exceedingly small minority. In the frog, the proportion of the white to the red is 1 to 16 in winter, and 1 to 6 in the summer. In man during health only 2 or 3 white occur to 1000 red.

(β) Their Size.—The white corpuscles of all classes, from Pisces to Mammalia, are of nearly the same size, though their companions the red differ largely in diameter in the various groups. The average diameter is about $\frac{1}{110}$ of a millimetre.

(γ) Their Structure.—They are akin to the embryonic cells. Their protoplasmic contents are granular. Sometimes the granules are very fine, at other times of a coarser nature. In the protoplasm are to be seen minute, clear, round spaces, probably filled with fluid—the vacuoles. Each corpuscle has one, two, or more generally three nuclei. They are specifically lighter than the red. They possess to a very considerable extent the power of changing their shape, and, though normally spherical, exhibit a great variety of outline, due to their amœboid movements. Like the Amœba, again, they can take into their interior minute solid particles that have been introduced into the blood.

(*e*) Red Corpuscles.—(α) Their Number.—As we ascend in our survey of the blood of animals, we find the number of the red corpuscles in relation to the white and to the mass of the blood as a whole steadily increasing. Vierordt and Welcker have estimated the number of them in a cubic millimetre of human blood at 5,000,000. Their proportion in the blood is in direct relation, not merely to the general temperature of the body, but to the muscular and nervous activity of the animal.

(β) Their Size.—Whilst the white, both in size and aspect, are alike in the blood of all Vertebrata, the red corpuscles of the different classes vary excessively in diameter and appearance.

In *Pisces* the diameter of the red corpuscles ranges from $\frac{1}{46}$ mm. to $\frac{1}{98}$ mm. In the Perennibranchiata or *Amphibia* where the gills are lasting, the corpuscles are largest. The siren has them $\frac{1}{16}$ mm. long and $\frac{1}{30}$ broad; proteus, $\frac{1}{18}$ by $\frac{1}{44}$; axolotl, $\frac{1}{25}$ by $\frac{1}{45}$; and amphiuma has them even larger still. In the frog (one of the *Amphibia* whose gills are not persistent) they are $\frac{1}{45}$ by $\frac{1}{66}$ mm. In *Reptilia* they range from $\frac{1}{60}$ to $\frac{1}{48}$ mm. In *Aves* from $\frac{1}{104}$ to $\frac{1}{88}$. The snowy owl has them $\frac{1}{62}$ mm. long and $\frac{1}{3}$ of that in breadth. In *Mammalia* the musk deer has red corpuscles only $\frac{1}{480}$ mm. in diameter; the goat, $\frac{1}{250}$; the sheep, $\frac{1}{209}$; the horse, $\frac{1}{181}$; the cow, $\frac{1}{180}$ to $\frac{1}{168}$; the pig, $\frac{1}{166}$; the dog, $\frac{1}{139}$; the seal, $\frac{1}{129}$; man, $\frac{1}{126}$; the whale, $\frac{1}{122}$; the elephant, $\frac{1}{108}$.

From this rather wearisome list of numbers are any generalizations to be drawn? Only perhaps two:—(i.) That if the blood corpuscles of animals belonging to the same order (of the class *Mammalia*, for example) be compared, there is some connection between the size of the animal and the size of its red corpuscles. The order Ungulata, whereof several examples have just been given, is an illustration of this. (ii.) That the size of the red corpuscles is inversely as the activity of the respiration of the individual. The largest corpuscles are in the slow-breathing *Amphibia*, and generally where respiration is carried on with great activity, as in birds, the corpuscles are smallest. If it is borne in mind that these corpuscles are gas-carriers, that in the active movers and breathers the tissues are more rapidly burnt off, and greater quantities of the gaseous products of their combustion are formed, while, at the same time, greater quantities of oxygen must be brought by the corpuscles to the tissues for their combustion,—if it is borne in mind that the smaller and the more numerous the corpuscles, the greater will be the extent of the surface of them exposed for gas absorption and evolution,—then there will be observed a connection between the activity of respiration and the increased number, with diminished size of the red blood corpuscles or gas-carriers.

(γ) Their Structure.—In all save the *Mammalia* they are of oval shape, and provided with a nucleus about $\frac{1}{3}$ the length of the whole corpuscle. In the *Mammalia* the red corpuscles are round and bi-concave, with the exception of the camel family of the order Ungulata, where the corpuscles are oval in shape. The general structure is probably the same throughout the vertebrate series. The nucleated or the non-nucleated corpuscles equally exhibit a colourless fibrous stroma, through which is diffused a semi-fluid coloured matter known as hæmoglobin, soluble in water, crystallizable, and consisting of carbon, oxygen, nitrogen, sulphur, and iron.

CHAPTER X.

CIRCULATION IN INVERTEBRATA.

IN the two preceding chapters the nature of the blood in the kingdom Animalia was considered. In this chapter and its successors the various methods of circulation in the different classes of animals will be discussed. The present chapter will be entirely devoted to the investigation of the circulation in the invertebrate classes. It will comprise an account of (A) those creatures wherein, although true blood is absent, yet there is a curious foreshadowing of a circulation. (B) Those wherein the movement of blood in the body cavity is the only form of circulation encountered, and there is no special circulatory apparatus. (C) Those presenting a system of vessels partially, at least, shut off from the body cavity. (D) The universality of a connection between the blood system and the exterior of the body in the invertebrates will be noticed.

(A) Invertebrata without True Blood.—(*a*) In the *Rhizopoda*, the only structures that can be in any way construed as having reference to a circulatory apparatus are the contractile vacuoles. These are spaces in the sarcode that are seen to contract at certain intervals. As they contract, radiating spaces are noticeable extending from them, and widening as the central vacuole lessens in diameter. Presently the central vacuole begins to expand, whilst the radiating vessels in connection with it narrow in diameter until they seem entirely to disappear. The contents of this system are probably water. It is almost certainly a respiratory apparatus, and under the head of Respiration will be more fully considered. But the chief end we are striving to keep in view—namely, the gradual specialization of functions—would be forgotten if attention were not called to the fact that, in this arrangement for distributing this watery fluid through the sarcode of the body by means of a pulsating central organ and vessel-like extensions thereof, there is a suggestion of the structural arrangement met with in the higher animals so distinctively in connection with the function of circulation. Here there is an association of a respiratory act with structures usually devoted to blood circulation.

(*b*) In the *Infusoria*, contractile vacuoles are present, and there is also a curious movement of the outer layer of the sarcode in company with the food vacuoles. It will be remembered that these food vacuoles pass, after quitting the abrupt termination of the œsophagus, through the sarcode along a very definite line. They trace the outline of the infusorial body as they pass along just within the contractile layer of the animal. With them the outer layer of sarcode is said to move.

(*c*) In the *Porifera* there is a circulation not of blood, but of water, carrying food matters and air for respiration through the body of the creature. The sweep of the cilia, wherewith certain of the amœbiform particles in the interior of the sponge are furnished, causes currents of water to enter at the small inhalent pores, and, after traversing the internal canals, to make their exit by the large exhalent pores. This circulation of water with food particles serves, along with other purposes, to bring tissue-forming materials to living and therefore wasting tissues. In this respect it resembles the true circulation in higher animals.

(B) Invertebrata whose Blood is not contained in any System of Vessels, but is free in the Body Cavity.—(*a*) In CŒLENTERATA and *Polyzoa*, the body cavity or enterocele contains a nutritive fluid. Even in the *Hydrozoa*, where that body cavity is still one with the digestive cavity, its contents are corpusculated. The movements of the body of the animals belonging to these classes cause a movement of the blood in the body cavities, a flux and reflux, a flowing and ebbing of the nutritive fluid. Here is the most general form of circulation. Once more the first appearance of a function is not associated with any particular structure. The whole body is concerned in its performance. In the compound CŒLENTERATA, this motion of the corpusculated fluid of the body cavity affects also the fluid in those extensions of the body cavities, through the common flesh or cœnosarc, that place in communication the interiors of the various members of the compound animal.

(*b*) In the next stage the body cavity is still the receptacle of the blood fluid, but that cavity is limited. No longer is the blood found bathing all the organs of the body as it ebbs to and fro in the large somatic cavity. The lacunæ or spaces in the mesoderm of the *Scolecida*, and the sinuses met with in the *Brachiopoda*, are the result of partial limitation of the general cavity of the body, are stages on the march onwards to those beings that have distinct portions of the great cavity enclosed within definite walls, and called vessels. Very noticeable is it, that with these lacunæ or sinuses the respiratory or water-vascular system still communicates.

(*c*) In the *Annelida* the body cavity is divided by thin partitions into several chambers, that communicate, however, with each other. The fluid contained in these loculi is not only nutritive; it acts also as a liquid fulcrum in the muscular movements of the body, so that there is presented in this case a blending of the two functions of circulation and of animal motion.

C. Invertebrata with more or less distinct Blood-vessels.—(*a*) General facts.—In the rest of the invertebrate classes, certain regions of the somatic cavity are enclosed within definite walls, and a true blood-vascular system commences. This system is not complete in any of the Invertebrata. At some point or points in the body the vessels will be found to terminate, and the blood will flow not within walls, but through lacunæ or spaces not bounded by any limiting membrane. It may be said that true capillaries are almost wanting below *Pisces*. At certain parts of the body, therefore, the old form of circulation is met with, and the blood is in the general cavity once again. The lower the animal, the more extensive is this lacunar circulation. The arteries are not provided with the three distinct coats that are met with in the Vertebrata. The heart is generally dorsal in situation and systemic—that is, its pulsations drive blood at once over the body generally, not to the respiratory apparatus first. The word 'pericardium,' that is used occasionally in the descriptions of the blood systems of Invertebrata, is an unfortunate and misleading one. The pericardium of *Insecta* and

Crustacea has no homology with the serous membrane that invests the heart of the vertebrate animals. It is, in truth, a large venous sinus, surrounding that long segmented vessel in the dorsal region of the body that is generally called the heart. From this venous sinus, blood passes into the heart by certain lateral openings provided with valves opening inwards. Yet another unfortunate name has been used in this connection. Certain parts of the venous system in the *Insecta* and *Myriapoda* have been designated portal. They represent, however, in no manner the portal system peculiar to Vertebrata.

(*b*) Circulation in the ARTHROPODA.—In the *Myriapoda*, *Insecta*, and the higher *Arachnida*, the long segmented dorsal vessel is called, not very correctly, the heart. From its chambers lateral vessels run, all of about equal size in the *Myriapoda*, some larger than others in the *Insecta*. These vessels have at no part of their course very distinct coats, and present few branches. They end mostly in lacunæ. These lacunæ all communicate with a sinus or vessel on the lower side of the body. Thence the blood passes to the respiratory organs, and then to the pericardium or venous sinus surrounding the dorsal vessel. The general arrangement of the circulation in *Crustacea* is the same as that just described; but the heart in the higher forms is far more condensed and defined. In the lobster it is a powerful quadrate organ, not presenting that succession of similar segments which is always a sign of lowness of organization. The arteries are large, definite in number and in distribution. There are contractile expansions at the base of the vessels conducting the blood to the gills.

(*c*) Circulation in the MOLLUSCA.—The *Ascidioida* present a phenomenon in connection with the circulation that is peculiar to them. It is the reversal at regular intervals of the direction of the blood current. The heart is without valves, and contracts with a wave-like movement. If the wave is from below upwards, the blood passes into an abdominal vessel, thence into transverse ascending canals that lead to the extraordinary network of vessels connected with the respiratory structures, into a dorsal vessel, and thence by a connecting branch to the posterior end of the heart. After a certain period, the wave of contraction through the heart, and the course of the blood, are generally reversed in direction; and the blood now flows from the ventral heart into the dorsal vessel down through the branching network into the abdominal or ventral vessel, and so to the anterior end of the heart. The higher molluscan classes have all of them well-marked hearts, generally with auricles and ventricles, arteries and veins, though the capillary system is still deficient. The hearts of *Gasteropoda* and *Cephalopoda* have valves and columnæ carneæ, or muscular projections on the inner walls of the heart. As the highest arthropod class has gill-hearts, so do the *Cephalopoda* possess contractile expansions at the commencement of the gill-vessels.

D. In the Invertebrata, the Blood-System is at one or more points placed in communication with the Exterior of the Body.—The body cavity of the CŒLENTERATA opens externally in many cases, probably in all. The water-vascular system of the *Scolecida* and their allies opens into the blood system on the one hand, communicates with the exterior on the other. The segmental organs of the *Annelida* are a medium of communication between the circulatory apparatus and the environment. Finally, in the organ of Bojanus, under its various forms in the MOLLUSCA, we have a more or less complex tube joining the blood system on the one hand with the exterior of the body on the other. In all Invertebrata, the blood system is not completely separated from the general cavity of the body, and that general cavity of the body has openings placing it in communication with the air or water wherein the animal lives.

CHAPTER XI.

CIRCULATION IN VERTEBRATA.

Pisces and Amphibia.

THE arrangement of the circulatory organs in the classes of the sub-kingdom VERTEBRATA forms the subject of this article and its successor. It is proposed to consider (A) certain general facts in connection with the sub-kingdom; (B) the circulatory organs in the five classes of VERTEBRATA.

A. General.—The chief things distinguishing the blood systems of the highest division of animals from those of the lower classes are, (*a*) the presence of a pericardium; (*b*) the presence of a portal system.

(*a*) VERTEBRATA, with the exception of the lowest member of the lowest class, the abnormal fish Amphioxus, have a pericardium. This must not be confounded with the badly-named pericardium of the Invertebrata. The pericardium of the backboned sub-kingdom is a true double serous membrane, enveloping the heart, and secreting between its two layers, after the fashion of serous membranes, a thin, watery, lubricating fluid.

(*b*) A portal system is met with in the highest division of the kingdom Animalia. Instead of the veins of the intestine returning directly by way of the *vena cava inferior* to the heart, their contents pass first through the liver, and after ramifying through that organ enter the *vena cava inferior* by way of the hepatic vein or ordinary vein of the liver. This secondary circulation, this passage of blood through a second set of capillaries after it has traversed those of the intestines, is peculiar to VERTEBRATA. The lower the class of VERTEBRATA under consideration, the larger is the number of vessels entering into the portal system. In mammals, the vena portæ is formed by the union of the veins of the stomach, intestines, omenta, pancreas, spleen, and gall-bladder. As we descend in the scale of VERTEBRATA, more and more numerous are the vessels entering into this vein that is to redivide in the substance of the hepatic gland. Especially noticeable in this connection is the fact that the three lowest classes, *Pisces*, *Amphibia*, *Reptilia*, have not only a hepatic portal system, but a renal one. The kidneys, as well as the liver, are traversed by a set of vessels, the result of the ramification of one that has been formed by the union of many capillaries, not by the subdivision of an artery. The name vena portæ is derived from the old notion that the digested food entered the body through this vessel. Therefore was the vein in question looked on as the 'gate' whereby food matters for the most part entered the body. The curious student of literature (a name that should be synonymous with that of the student of science) will call to mind that in his essay, *Of Empire*, Bacon refers to this very vessel, the vena porta (as he calls it), and symbolizes thereby the merchants of the state.

Whilst the above two structures, the pericardium and the portal vein, are the most distinctive marks of the vertebrate circulation, attention must be called to the frequency of those networks of blood-vessels known as *retia mirabilia*, or wondrous networks. Frequently in the dissection of Vertebrata, complex networks of vessels are met with that often serve the purpose of delaying the passage of the blood when possibly its regular onward flow would be injurious to the creature. Thus the carotid artery within the heads of some Ungulata, and especially of those that feed with the head lowered towards the ground, the artery of the anterior limbs of the sloth, the thoracic vessels of the Cetacea, all present *retia mirabilia*.

The changing of position in the heart of VERTEBRATA is a point worthy of consideration. In the lowest, or *Pisces*, the heart is placed close to the anterior extremity of the body. As we ascend we find the heart receding, but still remaining in the middle line of the body. Finally, in the highest Vertebrata the heart is even displaced from the position it has held in the middle line of the body, and becomes inclined towards one side.

B. The Circulatory Organs in the Different Classes.—(1) *Pisces.*—The course of the blood in this class is as follows :—The venous blood returning from the body enters the single auricle after passing through a very well marked dilatation, the sinus venosus. From the one auricle it passes into the one ventricle, thence to the arterial bulb, which at times shows traces of division into chambers, thence by the branchial arteries, very commonly in five pairs, to the gills. Traversing the gills, the blood enters the aorta through the branchial veins on the dorsal region, and through the branches of the aorta is distributed to the body generally. The vessels to the head are usually given off before the branchial veins join in the common aorta. The capillaries unite into veins that terminate in four chief returning vessels. The two anterior are the jugular veins, the two posterior the cardinal veins. The jugular and the cardinal of each side of the body join in a transverse duct, the duct of Cuvier. The two ducts end in the sinus venosus. The comparative lowness of type is, however, shown in the number of pulsatory vessels in *Pisces*. In many places the blood-vessels are found to be contractile. The function of the heart as the great contractile pulsatory organ is not clearly defined. Other regions of the blood system are still taking on some of the work of impelling the nutritive fluid on its course. Amphioxus has a great many veins thus pulsatile. The myxine or hag has the portal vein in the same condition. Other instances are the caudal veins of the eel, and the artery supplying the pectoral fins of the torpedo. Amphioxus, with its numerous hearts, is very suggestive of the Invertebrata, the majority whereof have no definite contractile organ driving the blood round the body, but a contractile system made up of many parts that are in not a few cases scattered over a wide area of the body.

More than a passing reference to the distribution of the blood of *Pisces* to the air-bladder, or rudimentary lung, is unnecessary here, as that organ and its blood supply will be considered more fully under the head of Respiration.

This class, however, must not be left without attention being called to the circulatory apparatus in the lepidosiren, or mudfish of the Gambia, the highest member of the group. This creature approaches the type of structure met with in the lowest members of the next class, the *Amphibia*. Of its six pairs of branchial arches, the first, fourth, fifth, and sixth are as those of *Pisces ;* but the second and third pass, without going through the gills, at once into the aorta, and also give off branches that join to form a single artery going to the air-bladder, or true lung.

(2) *The Amphibia.*—The adult members of the class represented by the perennial frog have a circulatory arrangement similar to that in *Reptilia.* The venous blood from the body enters the right auricle. Arterialized blood from the lungs enters the left auricle. Both auricles open into the one common ventricle. From this arises the aorta, carrying blood to the body generally, and the pulmonary artery conveying blood to the lungs. Here is a mixed circulation, as it is clear that the aorta will convey to the body not pure blood, but a mixture of pure blood coming from the lungs, and the impure fluid brought to the right auricle from the tissues of the body. Still, here is a great advance on the type met with in *Pisces.* There are in this class two auricles, each with a distinct office. One of the lowest members of the group, the Proteus, however, has not two clearly-defined auricles. It has one auricle with a septum partially dividing it into two. The ventricle, as a rule, shows no trace of division; it is still one simple cavity. As a most interesting foreshadowing of what is to be in the reptilian heart, is to be noticed the fact that the part of the one ventricle whence the pulmonary artery takes origin is thinner and weaker than the rest. To those who remember that the right ventricle of mammals is thinner and weaker as to its walls than the left, this statement will not be without significance. All of the *Amphibia* have, during the early period of their life, gills that are afterwards either aided in their work of respiration or superseded by lungs.

The members of the class that retain gills throughout their lives, despite the appearance of lungs, are called Perennibranchiata. Manifestly they are lower in the scale of being than those wherein the gills are temporary and not lasting. The difference between the two divisions is maintained in the blood system. Thus in all the *Amphibia* one main vessel quits the ventricle, and at once divides into branches right and left. In the Perennibranchiata there are four pairs. In the higher *Amphibia* of true aortic arches there are but two pairs. Pulsating vessels are still to be seen on the venæ cavæ, and sometimes on the iliac and the axillary arteries.

Finally, in this class it is necessary to consider briefly the changes in the blood system attendant on the gradual alteration in the respiratory system due to the more or less complete replacement of the gills by lungs. At first, there are three pairs of branchial arteries going to the gills from the bulbus arteriosus in front of the ventricle. The blood passing through them traverses the gill capillaries, and by the gill veins enters the aorta. But from each branchial artery runs a small vessel directly into the corresponding vein without passing through the gill apparatus at all. As the gills lessen in size, and the lungs appear and increase in size, these connecting vessels enlarge, and more and more blood goes through them at once into the aorta, whilst from the last of the pairs of arches are developed vessels passing to the lungs. Lungs, connecting vessels, right auricle, grow; the gills and the vessels traversing them diminish, until at last all the blood from the ventricle passing through the arterial bulb goes by way of the connecting branches directly into the aorta, and never reaches the gills at all.

CHAPTER XII.

CIRCULATION IN REPTILIA AND AVES.

THERE remains for consideration circulation in the three highest classes of the sub-kingdom VERTEBRATA. In *Reptilia* the course of the circulation is as in the frog. The reptilian, like the batrachian heart, has three cavities. The right auricle receives venous blood from the body. The left auricle receives arterial blood from the lungs. Both auricles open into the single ventricle. This contracting, forces into the aorta and into the pulmonary artery a mixture of bad and good blood. The circulation is not, therefore, of the excellent type encountered in birds and mammals. It is imperfect, and the class is a cold-blooded one. Its members have not the power of maintaining their body temperature at a certain fixed height. The temperature of their blood is dependent upon the temperature of the surrounding medium.

The ventricle of the reptilian heart is generally partly divided by an imperfect muscular septum. This septum is attached to the inner lining of the front wall of the ventricle, and partly divides that cavity into two. The portion to the right of the septum is called the *cavum pulmonale;* that to the left is called the *cavum venosum.* From the cavum pulmonale arise the *left* aortic arch and the pulmonary artery; from the cavum venosum arises the *right* aortic arch. The position of these arches is noticeable. The left arises from the right side of the ventricle. The right arises from the left side of the ventricle. But they cross one another, as in the once fashionable game of croquet the centre hoops were wont to cross. The two vessels curve towards one another in the middle line of the body, and unite in the common aorta. From the right arch of the aorta arise the principal blood-vessels to the head. Let the reader picture, then, a heart with three cavities, the right auricle receiving impure blood, the left auricle receiving purified blood, both opening into a common ventricle, this ventricle partially divided by a septum attached to its anterior wall; from the right of the two regions of the ventricle the left arch of the aorta and the pulmonary artery arising, from the left of the two regions the right arch of the aorta taking origin. Now let him imagine the ventricle contracting. The impure blood received from the right auricle is forced at once into the left aortic arch and the pulmonary artery. As the ventricle contracts, the free posterior edge of the septum is approximated to the posterior wall of the heart, until the partial partition becomes a complete one, and the right-hand portion of the ventricle, with its impure supply, is shut off from the left hand, that is receiving nutritious blood from the left auricle. Hence it follows that the right aortic arch receives nearly pure blood; and it is to be noted that it is from this arch that the vessels supplying the head take origin.

In the crocodile, the highest of reptiles, the incomplete septum of the lowest three classes becomes complete. The heart has therefore four cavities. At first sight the circulation in the crocodile would seem to be as complete as in a bird or a mammal. But two things militate against the perfection of this arrangement. In the first place, the left aortic arch still arises from the venous ventricle; and, as if to make assurance doubly sure, there is an aperture of communication between the two aortic arches where they cross one another. This aperture, known as the *foramen Pannizzæ*, permits the admixture of good with bad blood; but once more it is to be observed that the vessels to the head arise from the left aortic arch before its communication with the right.

At the origin of the aorta only two, not three, semi-lunar valves are to be seen.

All the class *Reptilia* have two descending and one ascending venæ cavæ.

(4) *Aves.*—In this class for the first time we meet with warm-blooded animals—that is, animals that have the power of maintaining a fixed definite temperature, no matter what may be that of the external medium. Thus the temperature of the blood of birds is a constant—namely, about 45° C. No matter what the temperature of the air is, the temperature of the bird's blood in health remains constant.

The disposition of the organs of circulation and the course of circulation in birds is the same as that in *Mammalia*. As the latter will be considered in the next article, it will suffice for the present to indicate the points of difference between the two classes.

(*a*) In the heart of birds there is a single valve between the right auricle and the right ventricle.

In the heart of *Mammalia* there is a threefold valve, the tricuspid.

(*b*) The arch of the aorta is single, and curves to the right-hand side of the body.

It will be well to consider for a moment the various arrangements of the aortic arches in the VERTEBRATA. In *Pisces* and *Amphibia*, in the larval condition, there are three or more aortic arches. In the adult *Amphibia* and the *Reptilia*, there is one pair of aortic arches; in *Aves*, a single aortic arch to the right side of the body; in *Mammalia*, a single aortic arch to the left side of the body.

(*c*) The carotid artery is deficient on the right side in the singing birds, on the left in the flamingo.

(*d*) The external thoracic artery is of exceptional size, because it has to supply the huge muscles for moving the wings. As the muscles for moving the wings are larger than the whole of the rest of the muscles put together, it is evident that the blood supply thereto must be excessive.

(*e*) The aorta, instead of dividing into two main arteries for the lower limbs, divides into a pair of arteries on each side. One of each pair is the crural, the other is the ischiadic.

(*f*) *Retia mirabilia*, or networks of blood-vessels, are met with at several points in the circulation of birds, as *e.g.* on the ophthalmic artery, the anterior tibial, and at the remarkable vascular structure in connection with the eye known as the pecten.

(*g*) There are two superior *venæ cavæ*.

CHAPTER XIII.

CIRCULATION IN MAMMALIA.

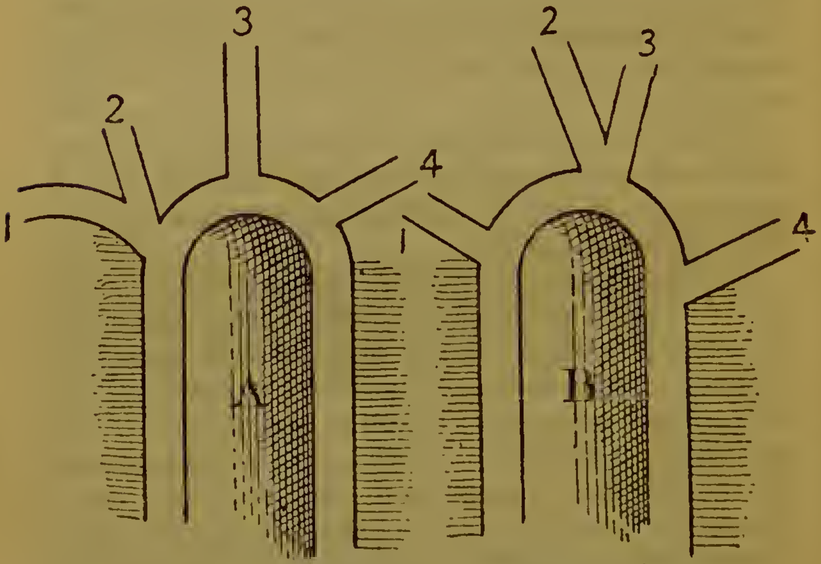
THE *Mammalia*, like *Aves*, are warm-blooded animals—that is, they have the power of maintaining their blood at a fixed temperature, no matter what may be that of the surrounding medium. The normal temperature in human beings is from 36° to 37° C. The temperature in the rest of the class does not range more than 2° or 3° on either side of this. Whilst both Aves and *Mammalia* are warm-blooded, the temperature of the blood in the former animals is about 10° higher than in the latter. It is almost unnecessary to remind the reader that birds are far more active in their movements than mammals, and that greater activity means higher blood temperature.

The circulation in *Mammalia* will be considered under the following heads:—A. The heart. B. The course of the circulation. C. *Retia mirabilia.*

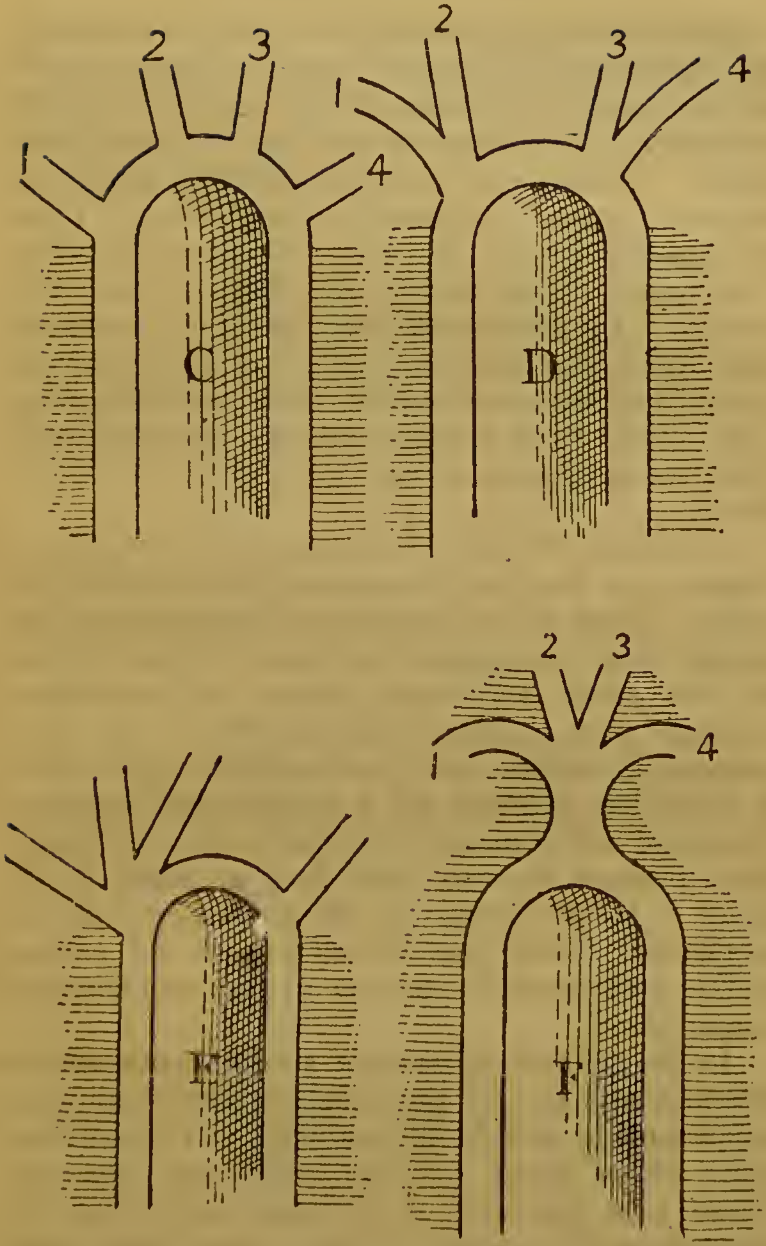
A. The Heart.—The heart throughout the whole of this class is constructed on the same plan as that of man. There are four cavities—the two upper, auricles; and the two lower, ventricles. Each auricle communicates with its corresponding ventricle, but the right side of the heart is completely shut off from the left. In truth, there are really two distinct hearts; and in the dugong, one of the order Sirenia, there is an actual separation of the two halves of the heart from each other. In all the rest of the class, even to the very highest genus, the external appearance of the organ presents indications of its double nature. During that earliest part of the life of all *Mammalia* which is spent within the maternal body, there is, however, a communication between the two parts of the heart. The aperture of communication is known as the *foramen ovale*. In the aquatic Carnivora, as the seal, this aperture remains constantly open, and the circulation, therefore, is less perfect. Occasionally, this persistence of the foramen ovale is met with as an abnormality in human beings, causing the condition known as *morbus cæruleus*. At the junction of the right auricle and right ventricle, folds of the inner lining of the heart are arranged so as to form a tripartite valve, permitting the passage of blood from the auricle to the ventricle, but preventing any reflux of blood into the auricle during ventricular contraction. This valve is called the tricuspid. In the corresponding position on the left side of the heart is a valve consisting of two folds, known as the mitral. In the Ornithorhyncus, the lowest of mammals, there is a reversion to the avian type, only one valve being met with in the place of the tricuspid.

B. The Course of the Circulation.—The venous blood returning from the body enters the right auricle, and passes thence into the right ventricle. From the right ventricle the blood is conveyed by way of the pulmonary artery to the lungs. After undergoing purification in those organs, it is returned by the pulmonary veins to the left auricle. From the left auricle it passes to the left ventricle, and thence into the aorta. The arch of the aorta is bent towards the left side of the body, not towards the right, as in birds. In man the arch gives off three vessels; the right-hand one of the three is called the innominate artery. It divides into two branches, — one is the subclavian, and carries blood to the right upper extremity; the other is the carotid, supplying the right side of the head and neck. The middle vessel of the three arising from the aortic arch is the left carotid, whilst the vessel that takes origin most to the left is the left subclavian. In the different orders of the class, varying arrangements of the aortic arch and its branches are encountered. These will be best understood by reference to the accompanying diagram, in all parts whereof 1 represents the right subclavian, 2 the right carotid, 3 the left carotid, 4 the left subclavian.

Diagram of the Arches of the Aorta in Mammalia.



A. Man, monkeys, mice, hedgehogs, sloth.
B. Elephant.



C. Cetacea.
D. Bat.
E. Carnivora, Marsupialia, Rodentia.
F. Ungulata.

After describing its arch, the aorta takes nearly the middle line of the body, lying a little to the left of the vertebral column, and giving off numerous branches. It is now known as the descending aorta. The arterial offshoots, dividing within the various organs, terminate in capillaries. These microscopic vessels, reuniting, constitute the veins. The veins finally return the blood to the right auricle. In *Mammalia* there are one ascending and one descending *vena cava.* It will be remembered that birds and reptiles have two descending *venæ cavæ.* The elephant and the ornithorhyncus have an arrangement similar to that met with in birds.

C. Retia Mirabilia.—Remarkable networks of vessels are met with in certain individuals of this class. Thus, in the carotids of most animals that graze, these networks are seen. The vessels of the orbits and nasal organs of herbivorous animals also present *retia mirabilia.* As these animals in feeding have to maintain the head in a dependent position for a considerable length of time, the utility of such networks will be evident; they prevent the too rapid flow of blood to the head. In the limbs of the sloth occur similar networks. These are in relation to the curious habits and unusual position of this tree-haunting mammal.

In the aquatic *Mammalia* special arrangements are met with in both the circulatory and respiratory apparatus, to enable the animals to remain some time under water. In the circulatory apparatus these take the form of arrangements to prevent the too rapid passage of blood to the lungs whilst the creature is beneath the surface of the water.

Networks on the intercostal arteries, and expansions in the course of the iliac veins, are the most frequent structural arrangements for this purpose. They are to be seen in the blood systems of the Cetacea and the Sirenia.

CHAPTER XIV.

RESPIRATION.

AS the various organs of living bodies perform their functions, the tissues of those organs are consumed. The four principal elements in the tissues of organized bodies are carbon, hydrogen, oxygen, nitrogen. In that decay which is the necessary accompaniment of work, carbon and oxygen unite to form carbon dioxide, or ordinary carbonic acid (CO^2); hydrogen and oxygen unite to form hydrogen oxide, or water (H_2O); hydrogen and nitrogen unite to form hydrogen nitride, or ammonia (H^3N). These three compounds are the chief *ultimate* products of decomposition of working tissues. The intermediate stages between the complex materials of muscles, nerves, and other organs of the living animal body, and these three comparatively simple compounds, are possibly represented by 'extractives.' The chemical analysis of any secretion or of any organ reveals the existence of certain substances, complex and but little understood. From the methods used in separating these from their surroundings by means of water, alcohol, or ether, these substances are known generally as 'extractives.' Such are creatin ($C^4H^9N^3O^2$), creatinin ($C^4H^7N^3O$), leucin ($C^6H^{13}NO^2$), and sarkin ($C^5H^5N^4O$).

It is possible that some at least of these bodies may represent stages in the decomposition of the more highly-organized materials, such as albumin, myosin, gelatin, that enter into the chemical composition of the tissues of the organs of the body;—that they are intermediate between these active living materials and the carbon dioxide, hydrogen oxide, and hydrogen nitride, into which these living compounds, paying the inevitable penalty of doing work, ultimately decompose.

These three products of decay must be eliminated from the living body if it is to remain living. The separation of them from the blood is effected by the process of secretion (*secerno, secrevi, secretum*). The separation of them from the body is effected by the process of excretion. The three principal excreting organs are the lungs, the skin, the kidneys. Each of these helps in carrying off from the body all three of the ultimate products of decay. Each, however, gets rid principally of one of the three excretory products. The lungs primarily are the eliminators of carbon dioxide, in lesser degree of hydrogen oxide and hydrogen nitride. The skin primarily is the eliminator of hydrogen oxide in the form of steam. Through the kidneys especially nitrogenous excretions are poured forth: these, after escape from the body, evolve hydrogen nitride or ammonia.

Respiration, the function of the lungs, is therefore on the one side the elimination of the gaseous products of decay, in the form of carbon dioxide principally, with steam and ammonia in smaller quantities. But respiration is more. This combustion of the tissues involves the supply of oxygen to them. Combustion is in the main a union of bodies with oxygen. This gas must therefore be supplied from its great storehouse, the air. This also is the work of respiration, which may therefore be defined in full as *the elimination of the gaseous products of tissue-combustion, and the introduction of the oxygen necessary for that combustion.*

It is proposed to speak first of the respiration of plants. The usual statement encountered in all books until quite recently, and to be encountered unfortunately even in recent publications, is, that the respiration of plants is the converse of that of animals. Plants are said to breathe in carbon dioxide and to breathe out oxygen. This statement seems to have arisen from that looseness of phraseology, the natural outcome of looseness of thought, that it should ever be our earnest endeavour to suppress. It has arisen from the confusion between two distinct functions performed by the green parts of plants. These green parts breathe and feed.

Breathing.—The respiration of plants, like that of animals, is the elimination of the gaseous products of tissue-combustion, and the introduction of the oxygen necessary for that combustion. As in animals, an important element of plant tissues is carbon, therefore an important product of decay is carbon dioxide. This process of giving off the carbon dioxide gas is perhaps not confined to green structures. As in the lower animals, it is probably the work of all the surface of the plant.

But plants also feed upon air, and a largely important constituent of their food is carbon dioxide, the very gas they are breathing out. The green parts of plants take from the air carbon dioxide, retain the carbon thereof for tissue forming, and give out the oxygen. The action of plants on the air is therefore twofold. In breathing they remove oxygen, yield carbon dioxide. In feeding they remove carbon dioxide, yield oxygen. But the feeding process is far more excessive than the breathing process. The former masks to the unobservant eye the latter. The total effect of plants on the air is the converse of the total effect of animals thereon, but it is not a respiratory effect. Indeed, in the night time, when plants feed not, but the continuous process of breathing still is, carbon dioxide in small quantities, yet carbon dioxide, is evolved. To say that the respiration of plants is the converse of that of animals, is to substitute for an accurate definition of respiration the vague statement that 'respiration is the effect of plants or animals on the air.' To say that the respiration of plants is the converse of that of animals, is as accurate as to say that a man who drinks soda-water or champagne is breathing in carbon dioxide.

In this connection may be studied the relationship of the three great kingdoms of nature—mineral, vegetable, animal—to each other. The vegetable kingdom feeds mainly upon the mineral. The three chief food-stuffs of plants are carbon dioxide, water, ammonia. The first is composed of carbon and oxygen, the second of hydrogen and oxygen, the third of hydrogen and nitrogen. The three mineral food-stuffs, therefore, supply to the plant the four elements—carbon, hydrogen, oxygen, nitrogen—that make up the greater part of living bodies. By the living plant these elements are grouped up into more complex compounds than the carbon dioxide, water, and ammonia of the mineral kingdom. Such are the vegetable acids, the amyloid or starchy bodies, the sugars, the alkaloids. The animal kingdom in its turn feeds upon the vegetable, directly in the case of herbivorous, indirectly in the case of carnivorous animals.

The starches and sugars, and other vegetable substances taken into the animal organism, are converted into yet more complex bodies, such as albumin and gelatin. So complex are these bodies that generally no formula can be certainly assigned to them; only percentage composition can be given. Finally, all living beings in their decay break up for the most part into carbon dioxide, water, ammonia, restoring to the mineral kingdom the same three compounds that plants are ever removing therefrom. The mineral kingdom, therefore, may without a very great stretch of fancy be said to feed to some extent upon the two higher kingdoms. The subjoined table, showing the chemical composition of the plant food-stuffs, of some plant products, and of one or two animal substances, may be of help in the comprehension of this great food circulation of the world:—

Mineral.
Carbon dioxide, CO^2.
Water, H^2O.
Ammonia, H^3N.

Vegetable.
Oxalic acid, $C^2H^2O^4$.
Starch, $C^6H^{10}O^5$.
Caffein, $C^8H^{10}N^4O^2$.

Animal.
Albumin, C 53·5, H 7, N 15·5, O 22·4, S 1·6.
Gelatin, C 50·9, H 7·2, N 18·3, O 23, S ·56.
Protagon, $C^{232}H^{240}N^4PO^{44}$.

Products of Decay.
Carbon dioxide, CO^2.
Water, H^2O.
Ammonia, H^3N.

CHAPTER XV.

RESPIRATION BY THE GENERAL SURFACE, AND BY MEANS OF AIR DISSOLVED IN WATER.

THE function of respiration, or breathing in animals, will be considered under the following heads:—A. Breathing by the general surface. B. Breathing of air dissolved in water. C. Breathing of air directly.

A. Breathing by the General Surface.—Once more in the study of a particular function we find that in the earliest forms of animals that function is performed by no special part of the body. In those most lowly organized beings, constructed on the same model as a Gromia, the working of the tissues involves the formation of carbon dioxide. That carbon dioxide must be eliminated. Probably it is eliminated into the surrounding water from every point of the surface of the body, whilst at the same time oxygen is taken in. In the sub-kingdom CŒLENTERÁTA, the two classes *Hydrozoa* and *Actinozoa* have no higher form of respiration than this general one. The fluids within their comparatively thin body walls are in close relationship to the water in which they live. That water holds air in solution, and the whole ectodermic lining serves as a respiratory organ. In the *Porifera* or sponge class, or at least in those members of it through whose organization a constant stream of water flows, respiration is probably effected by means of the air dissolved in the water. In the circulation of this water through the ordinary fresh-water sponge, there seems to be a remarkable fusion of the three functions of digestion, circulation, and respiration. This, the sole method of respiration in the lowest animals, is a method of respiration in all. Whatever other breathing organs may appear, the general surface of the body is in all animals a breathing organ. Thus there are few more effectual ways of terminating the existence of the experimental frog than by varnishing it. It is worthy of remembrance that in higher animals even than the frog, the skin is still a distinctly respiratory organ. Thus, for every thirty cubic inches of carbon dioxide evolved from the lungs of a human being, one cubic inch of the same gas is evolved by this most general method of breathing.

B. Breathing of Air dissolved in Water.—The next stage in the differentiation of the function of breathing is that wherein the interchange of oxygen and carbon dioxide takes place at certain specialized regions, but where the air is not brought into direct contact with the circulating fluid. The air for respiration is dissolved in water. Of this method there are two conditions—(*a*) respiratory organs internal, (*b*) respiratory organs external.

(*a*) Internal.—Three forms of this method of respiration present themselves: (i.) Contractile vesicles. (ii.) Water-vascular system. (iii.) Pseudhæmal system.

(i.) Contractile Vesicles. — If the microscopic worker is studying Amœba or Paramœcium, he notices at intervals the following phenomena. At a certain region in the creature, a space appears to dawn. As this steadily expands, it is evident that its contents are liquid. Suddenly, when a certain size has been attained, contraction takes place; the space seems to vanish, whilst canals radiating therefrom simultaneously appear. There is probably a central contractile organ, and radiating therefrom a series of canals. When the former is full, the latter are empty. When the canals are filled with fluid, the central vesicle is empty. The fluid is apparently water, but almost certainly has air dissolved in it. Probably this system communicates with the exterior. Thus is brought into contact with the working tissues oxygen dissolved in water. This form of respiratory apparatus is met with in the majority of the *Rhizopoda* and the *Infusoria*.

(ii.) Water-vascular System.—In the lower classes of the sub-kingdom ANNULOSA, such as the *Scolecida* and *Echinodermata*, an extension of the preceding system is encountered. The microscopic contractile vesicle of Amœba becomes one or more pulsating sacs. The indefinite wall-less canals of Amœba become a series of longitudinal vessels with distinct walls. The inner surface of these vessels is provided with cilia. Here, then, is a system one part of which is contractile, and the other part ciliated. Its contents are probably water with air dissolved therein. This system communicates with the exterior. The ambulacral system of *Echinodermata*, connected with their motor organs, and to be described more fully in a later article, seems to be an offshoot of the water-vascular, specially adapted for motor functions. Here is homology, but not analogy. Structurally, the two systems are similar; functionally, they are distinct.

(iii.) Pseud-hæmal System.—In the class *Annelida*, whereof the leech and the earthworm are the most prominent types, a similar system of vessels to that described under the preceding head occurs, but its contents are coloured. The leech, for example, has four longitudinal vessels containing this coloured fluid. Not unnaturally these were regarded in the old times as circulatory in their nature. But blood must be nutritive, and is corpusculated. The fluid in the vessels of *Annelida* is certainly not corpusculated, and is probably not nutritive. Its colour is due not to red corpuscles, as in the mammalian blood, but to some colour matter in solution. According to Professor Ray Lankester, this colour matter is closely allied to, if not identical with, the hæmoglobin of the mammalian red blood corpuscle. In reality the fluid contained in this system is a respiratory fluid, and contains air in solution. The pseud-hæmal (or false blood) system communicates once again with the surrounding medium. This communication of the respiratory system with the water or air in which the animal lives possibly serves the purpose of air change. There must be a constant accumulation of carbon dioxide in the respiratory fluid, a constant diminution of the quantity of oxygen. The oxygen must be restored, the carbon dioxide banished. Both these desirable ends are probably attained by means of this ever-recurring communication between the water-vascular system and its homologues on the one hand, and the animal's environment on the other.

CHAPTER XVI.

ON RESPIRATION BY MEANS OF AIR DISSOLVED IN WATER.

IN the preceding chapters have been considered respiration in general, and in particular respiration in animals (A) by the general surface, and (B) through the medium of air dissolved in water. Under the latter head two methods present themselves: (*a*) where the water with air dissolved in it is introduced into a system of internal vessels; (*b*) where the water with air dissolved in it passes over certain organs, usually external, called gills. This second method of breathing air dissolved in water is the subject of the present chapter.

Those animals whose respiratory organs take the form of branchiæ or gills will be studied herein. If a definition of gill may be ventured upon, it is an organ formed by a modification of the external lining of the body for the purpose of breathing air dissolved in water. The gills of all Invertebrata are external in their nature.

(i.) *Brachiopoda.*—The old name for this class, Palliobranchiata (*pallium*, a mantle), shows that here is perhaps the most rudimentary and general form of gill apparatus. The whole of the mantle, or external lining of the body, is subservient to respiration. No special region thereof is marked off into distinct branchiæ. In one sense this form of respiration is similar to that first discussed amongst animals—that is, respiration by the general surface. But here the interchange is not between air dissolved in water and the general fluids of the body, but between the air dissolved in the water and the gases contained in the special fluid, blood.

(ii.) *Annelida.*—As might be expected in the lowest form that presents gills, we have an arrangement of a transitional nature. In many of the *Annelida* the respiratory organs present a combination of both of the methods marked (*a*) and (*b*). The pseud-hæmal vessels are vessels whereby air dissolved in water is carried into the various regions of the body. In the order Dorsibranchiata certain extensions of the body wall are formed, and into these pass special branches of the pseud-hæmal system. Possibly fresh air from the surrounding water is absorbed by the fluid in the vessels within these gills.

(iii.) *Crustacea.*—The *Crustacea* are the only other annulose class in the possession of gills. The gills in this class contain true blood-vessels of a venous nature. The carbon dioxide in this impure blood passes out into the water around, whilst the oxygen of that air passes into the blood. The branchiæ of Crustacea are attached to appendages of the somites; the gill-bearing appendages are generally those of the thoracic region of the body. The gills are either broad and plate-like, or the broad lamellar gills are shredded up into a number of narrower filaments. It is, of course, necessary that the water in contact with gills should be constantly changed. Various are the methods whereby this change is effected. Thus, in the lobster and the higher Crustacea, the gills are lodged in a cavity roofed over by the shell or carapace. In front of this gill chamber, on each side of the body, is a broad and fringed organ, attached to one of the maxillipedes or feet jaws. This is called scaphognathite. These scaphognathites are in constant motion backwards and forwards. They act as sweeps, removing the water from in front of the anterior opening of the gill covering, and causing a flow of water in at the posterior aperture, and over the gills.

(iv.) *Lamellibranchiata*, and the rest of the molluscan classes above them, with the exception of some of the *Gasteropoda*, have well-marked branchiæ, usually enclosed within gill chambers. The gills of this particular class are broad and plate-like; the water in contact with them is changed by means of cilia—that is, microscopic, structureless organs constantly sweeping to and fro. A similar arrangement for the changing of the water is met with in the Gasteropoda that breathe by gills, and in the two highest classes, the *Pteropoda* and the *Cephalopoda*. In the *Gasteropoda* the gills are not plain and plate-like, but dendritic—that is, tree-like, or divided into a number of branches. The *Cephalopoda* present two distinct orders—the Tetrabranchiata, with two pair of gills, as represented by the nautilus, and the Dibranchiata, represented by the cuttle-fish. It will be anticipated that the Tetrabranchiata, with the larger number of gills, are the lower order. The water is conducted to the gill chambers of the Dibranchiata by means of a muscular funnel, the infundibulum, whose aperture is situated beneath the head. This infundibulum is formed by the union of the epipodia of the foot. The respiratory organs of the *Branchio-gasteropoda*, while presenting the same general structure as that described above, vary exceedingly in their position and relation to other parts of the body. Thus the very orders of this important class (for example, Nudibranchiata and Tectibranchiata) are founded on the nature of the respiratory organs.

(v.) *Polyzoa.*—In this, the lowest of the molluscan classes, we have, perhaps, the representative of the first stage in the evolution of the respiratory apparatus of the lower Vertebrata. Reference is not made here to the extensions of the body wall that perforate at many points the shell, and bring the chylaqueous fluid of the general cavity into closer relationship with the water around. The structure of special interest is the dilated pharynx, the full importance of which will be better comprehended after the account of the next class.

(vi.) *Ascidioida.*— The ascidian has been suggested by Mr. Darwin as the representative of the point at which the vertebrate sub-kingdom began to work off from primordial forms common to it and to the molluscan. The similarity of its respiratory apparatus to that of the lowest fish is a strong argument in favour of this view. The dilated pharynx of *Polyzoa* becomes in the ascidian class not only dilated, but perforated. The apertures are provided with cilia, and a constant stream of water enters at the mouth, and passes into the pharynx through the ciliated openings, and thus into the atrial chamber, and out of its aperture into the water in which the creature lives. The walls of the pharynx are richly supplied with blood-vessels. The significance of the dilated pharynx of *Polyzoa* will now be more evident.

(vii.) *Amphioxus* is the lowest of the class *Pisces*, and therefore the lowest of the VERTEBRATA, and has a respiratory arrangement precisely similar to that of Ascidia. The name of the order whereof it is the solitary representative, Pharyngobranchii, is founded upon this peculiarity. In the next chapter an endeavour will be made to show how, from this perforated, ciliated pharynx, is derived the arrangement of branchii characteristic of the rest of the fishes, and of the larval form of the *Amphibia.*

CHAPTER XVII.

RESPIRATION—*continued.*

THE gills of the Invertebrata have been studied, and those met with in the vertebrate subkingdom will be considered in this chapter In the lowest class, *Pisces*, the branchiæ are constant. In the *Amphibia*, they are present in the larval system as the sole organs of respiration, and in the adult are either accompanied or entirely replaced by lungs.

In all VERTEBRATA, at one period in the development of the embryo, along certain lines transverse to the axis of the body, thickenings appear. These thickenings are upon each side of the body towards the anterior end. As they increase in size, the integument between them thins away until between the thickenings clefts are formed. The clefts are the visceral clefts; the thickenings are the visceral arches. They are peculiar to the VERTEBRATA. The first pair of visceral arches united form the lower jaw, the second and third pairs in man form the two pairs of cornua or horns of the bone to which the tongue is attached—that is, the hyoid. The higher VERTEBRATA have no more than these three pairs; but the fishes and *Amphibia* have a much greater number of visceral arches, to which are attached the gills. The water for respiration in fish is constantly being taken in by the mouth, and then forced by muscular contraction out at one or more lateral apertures on each side over the gills. These last lie in gill chambers, between the pharynx and the skin. Their lining membrane is an extension of the epithelium of the mouth, and is richly supplied with venous blood by the branchial arteries. The water that has bathed the gills escapes by one, or rarely more than one, external opening on each side that is guarded by the gill-cover or operculum. The operculum is a homologue, or representative in structure of the pinna, or cartilaginous portion of the external ear, in the higher animals. It will be noticeable how this arrangement of gill apparatus is founded upon, and is an extension of the respiratory pharynx of Amphioxus. The different orders of the class *Pisces* have varying arrangements of the branchial apparatus.

1. Pharyngobranchii have as sole representative the Amphioxus already discussed. 2. The Marsipobranchii include the lampreys and the hags. This order has sac-like gills of a comparatively simple nature. The lamprey has several gill openings on each side instead of one. Here, once more, the repetition of similar parts is a sign of lowness of organization. 3. Teleostei (the majority of fishes) have pectinated—that is, comb-like or tufted—gills; and the general arrangement of the respiratory apparatus is that described in the preceding paragraph. 4. Elasmobranchii, the shark and ray order, present pouch-like gills. 5. Dipnoi, including, or rather identical with, the Lepidosiren or mud-fish of South America, is the highest order of fishes. The name of the order points to the fact that there are two methods of breathing. Thus Lepidosiren has rudimentary external branchiæ, internal working ones, and, in

addition to these, true lungs. These lungs, as will be shown hereafter, are homologically the swim-bladder of ordinary fish. The two distinct kinds of branchiæ in this order are not without interest when compared with the respiratory organs in the larval condition of *Amphibia.*

The permanent condition in *Pisces* is a transitory one in the majority of the *Amphibia.* But while it is only transitory in the better known members of that class,—the frog and the toad,—the interesting gradation between the piscine and amphibian respiration commenced by Lepidosiren is completed by the Perennibranchiata. These are amphibians that retain the gills of the larval condition throughout, and have, at the same time, very excellent lungs. Axolotl is the most familiar example of the perennibranchiate *Amphibia.*

When any member of the caducibranchiate *Amphibia*—that is, *Amphibia* in which the gills are not persistent—quits the egg, it is in its respiratory organs, as in everything else, to all intents and purposes a fish. It possesses gills; but these are external, not enclosed in a definite cavity on each side of the head, as they are in fish. Fringe-like, they extend from the head of the tadpole, or other larval condition of the Amphibian, and floating in the surrounding water bring the venous blood within them into close relationship with the air dissolved in the water around. After a time, the skin on both sides of the head of our young Amphibian begins to grow over these external gills. At length they are both covered by the integument, the fold whereof represents, as in *Pisces,* the pinna or cartilaginous part of the mammalian ear. In fish, though the skin encloses the gills, yet are left two gill openings—one on each side—for tne escape of the water that has passed over the gills and aerated the blood therein. In *Amphibia*, or at least in the higher forms of the class, only one such aperture is to be seen. The gills on one side of the head are completely enclosed. In all other respects, however, the respiration of the larval form of the *Amphibia* is as that of *Pisces*. Even in the adult forms of certain members of the class, the branchiæ are persistent, and in some cases are even to the last of the first or external form. But in the majority of the class, as development advances, the respiration by means of gills is gradually superseded by the higher form of respiration by means of lungs. This is a higher form of breathing, inasmuch as the air to be respired comes at once into direct contact with the vascular lining membrane of the respiratory apparatus, and is no longer brought dissolved in water. As the Amphibian grows, therefore, its gills become replaced by lungs. Less and less blood flows directly from the heart to the gills, and these organs diminish in size and finally become reduced to functionless rudiments, wherein no respiration is occurring. The lungs, in the meantime, receive larger and larger supplies of blood, and increasing in size are at length the sole internal organs of breathing. I say internal, because the skin in this class, more than in the majority of the higher classes, retains its constant function in the lowest animals, and is still a respiratory organ. The manner wherein the venous blood-supply from the heart to the gills in the earlier conditions of amphibian life is diverted from those organs, and made to pass for purification to the lungs, has been considered in the former chapters on the circulation of the blood.

CHAPTER XVIII.

RESPIRATION—*continued.*

HITHERTO, in the study of the law of progress from the general to the special, as exemplified in the respiration of animals, we have only met with cases where the air for breathing has been dissolved in water. The higher form of respiration is that to be now considered, where the air that is to yield oxygen and to receive carbon dioxide comes directly into contact with some vascular membrane whose vessels are veins charged with impure blood.

There are three principal types of this form of respiration:—(1) The breathing of air not dissolved in water by means of the general surface; (2) Tracheal breathing; (3) Pulmonary breathing.

(1) *The Breathing of Air by the General Surface.*—Repetition can scarcely be too frequently employed in instruction. Once more, therefore, the writer ventures to remind the student that at first all functions are performed by all parts of the body indifferently, in every sense of the word. In the lowest animals, amongst those that breathe air dissolved in water, it will be remembered that the air-laden water was brought into contact with the surface of the body generally, and not of a special region. It can hardly be said that there are any

actual cases among the lower classes of the animal kingdom of respiration *solely* carried on by interchange of gases between the air and the general surface of the body, but there are probably certain creatures in whom respiration is at times effected in this manner. The sea anemones, at low tide, possibly absorb oxygen from the air, and give out carbon dioxide by means of their delicate ectoderm. Certainly all animals, even to the highest, that breathe air directly, whether by tracheæ or lungs, at the same time respire in lesser degree by their general surfaces. This respiration by the integument is most marked in those whose integument is unprotected by such epidermal developments as hair, feathers, or scales. Thus the naked-skinned frog breathes, in some part of the year, more by his skin than by his lungs.

(2) *Tracheal Breathing.*—The evolution of the respiratory apparatus for breathing air directly, seems to have passed along similar lines to those noticed in the evolution of the respiratory organs of animals that breathe air dissolved in water. In the study of these last, we saw that after respiration by the general surface, the next stage was the introduction of air dissolved in water into the body by means of a system of tubes, as in the water-vascular and pseudhæmal systems. The highest condition of this form of breathing is the branchial. In all animals that breathe by branchiæ, the aeriferous water is no longer carried into many regions of the body by means of tubes. It is brought into one special region of the body where the gills are. In aerial breathers, after respiration by the general surface, the next stage is the introduction of air into the body by means of a system of tubes. In all animals that breathe by lungs, the air is no

longer carried into many regions of the body by means of tubes. It is brought into one special region of the body where the lungs are.

Those aerial breathers whose bodies are traversed by a tube system will now engage our attention. They are only met with among the classes of the sub-kingdom ANNULOSA. The three classes, *Myriapoda* (centipedes and millepedes), *Arachnida* (including scorpions, spiders, and cheese-mites), and *Insecta*, all have respiratory organs on this model.

Myriapoda.—Examination of the lateral parts of the somites or body segments of a millepede reveals the presence of small apertures called stigmata. These lead at once into tubes, which ramify amongst the various organs of the body. Entering at these stigmata, and passing through the tubes and their branches, air is brought into contact with the blood-vessels distributed on the walls of the tubes. In the centipede, a precisely similar arrangement exists, with this exception—the stigmata or openings along one side of the body are met with only in alternate segments. Their fellows on the opposite side of the body are also arranged in alternate segments, and in such fashion that each somite is provided with one stigma, the stigmata succeeding each other, therefore, on alternate sides of the body.

Arachnida.—In some of the lowest of the *Arachnida*, there is no indication of any higher form of respiration than that by the general surface. In the three better known members of the class whose names are given above, we have—(*a*) in the cheese-mite, simple tracheal respiration; (*b*) in the spider, two stigmata opening into tracheæ, and several others opening into pulmonary or lung sacs; (*c*) in the scorpion, all the stigmata opening into pulmonary cavities. The structure of these rudimentary lungs in *Arachnida* will be considered under the third head in aerial respiration.

Insecta. — The class of insects breathes by tracheæ, never by lungs. The stigmatic openings are restricted to the somites of the third region of the body, or abdomen. Very frequently these apertures are occupied by perforated plates. These sieve-like structures filter the air as it passes through them, and free it from mechanical impurities. Each stigma does not, as a rule, open directly into a trachea, but into an ante-chamber whence the tracheal tube takes origin. This ante-chamber is frequently provided with a series of little plaits, folds of its lining membrane. These epiglottides, as they are badly called,. probably serve the same purpose as the perforated plate in the stigma. Structurally they remind us of the folds seen in the first form of lungs to be described hereafter. The tracheæ are much more extensive in their branchings in the *Insecta* than in the other two classes, and in some of the more powerful flying insects present dilatations called air sacs. The larger tracheæ have three coats; the most internal —that is, the one in contact with the air—is in direct continuity with the integument, and is integumental in its nature. The middle coat is a spiral coat of chitin, serving to keep the tube open, and calling to mind the cartilage rings in the windpipe of higher animals. The external coat is of connective tissue, and blends with the body structures around. In the aquatic larvæ of certain insects tracheal gills are present. These are delicate folds of the integument richly supplied with tracheæ. The air dissolved in water wherein or whereon these creatures flit to and fro, passes into the tracheæ. This phase of respiration is suggestive of the gills of certain *Annelida*, into which pseudhæmal vessels enter. Two general ideas suggest themselves in conclusion. The first is the similarity in structure of the tracheæ in insects and the spiral vessels in plants (the vessels of plants are regarded as air carriers). The second is that the greater the activity of an animal, the more complete is its respiration. Insects, the most active of Invertebrata, have this most complex system of tracheæ, wherein the blood is brought into direct contact with the air at an almost infinite number of points.

CHAPTER XIX.

RESPIRATION—*concluded.*

THE lowest forms of animals breathe by their general surface alone. Animals higher above them in the scale breathe by means of air dissolved in water. A still more advanced method of respiration is the breathing of air directly. This direct respiration of air is accomplished through the medium of tracheæ or of lungs. We have to consider in this chapter respiration by the lungs.

Two classes only below the VERTEBRATA present structures that can be regarded as pulmonary. Of these two classes one belongs to the sub-kingdom MOLLUSCA, the other to the sub-kingdom ANNULOSA. The molluscan class is the *Gasteropoda.* Not all the members of this class breathe by lungs. The snail and the slug constitute the whole of the division Pulmo-gasteropoda. On one side of the neck of the snail is seen a small opening leading into a simple cavity. This cavity is lined with vessels or sinuses containing impure blood. Air from the exterior entering at the opening, yields oxygen to the venous blood, and receives therefrom the carbon dioxide. This is the simplest form of lung to be met with in the Animal Kingdom. One may, perhaps, venture to compare it to a single so-called air cell of the mammalian lung. In each case there is an internal cavity lined by a delicate membrane supplied with impure blood and having air in contact with its free surface.

The Annulose class is the *Arachnida*. The two highest animals in this class, and, at the same time, the best known, are the spider and the scorpion. The spider breathes partly by tracheæ, but the majority of the openings in its body wall lead into pulmonary sacs. These are on the same general plan as the rudimentary lung of the Pulmo-gasteropoda, but are of a rather more advanced type. The vascular lining membrane is no longer perfectly smooth. It is extended into several folds that are in close relationship to the margins of the openings, and afford a considerable increase of surface for the contact of blood and air.

The scorpion, which is the highest of the Arachnids, has no tracheal system, and breathes wholly by pulmonary sacs.

VERTEBRATA.—All the classes of this sub-kingdom present organs that, structurally at least, are lungs.

(1) *Pisces*.—The true respiratory organs in this class are, of course, the branchiæ or gills. A large number of the members of the class, however, have swim bladders. The swim bladder is a homologue, and probably not an analogue of the lung. It has the structure and the anatomical relations of the lung, but does not appear to perform the functions of that organ. The swim bladder is usually placed just beneath the vertebral column. The lungs of the higher classes also lie at the back of the thorax, on either side. Its duct, when it has one, opens into the alimentary canal. The tracheæ and lungs of the higher classes in their earliest phase

of development are offshoots of the œsophagus or anterior region of the alimentary canal. Special arrangements of overlapping bones, moved by special muscles, act upon the swim bladder and serve to expel the air therefrom. So are the lungs of the higher animals compressed by the bony and muscular framework of the thorax wherein they are lodged. But the air in the swim bladder does not appear to be derived from the exterior. It is more probably secreted or separated from the blood of the fish. Its composition is not that of the ordinary air. Furthermore, the blood-vessels that are found in the walls of the swim bladder are arterial, not venous. Clearly, therefore, it cannot be functionally a lung. Its office seems to be rather that of altering the specific gravity of the fish. An expulsion of air from the swim bladder would render the fish relatively heavier, and enable it to sink through the water. Here is an organ structurally connected with the respiratory apparatus of other vertebrates, but functionally connected with the movements of the body of fishes.

All VERTEBRATA above *Pisces* breathe at some period or other of their lives by lungs. (2) The *Amphibia* commence their extra-oval life as gill breathers. After a time the function of purifying impure blood is gradually transferred from the branchiæ to the lungs. As these latter organs develop, the venous blood of the body passes through them in ever-increasing quantity, until at length the gills are reduced to mere functionless rudiments, and the lungs have taken on fully the function of respiration. But the lungs in this class and in the next ((3) *Reptilia*) do not present the same complexity that they present in the higher vertebrates. In not a few cases the subdivision of the lung is confined to its upper region, and the lower part is a simple undivided sac. Even in the superior portion, where subdivision of the bronchi or air tubes does occur, it is not carried out to any considerable extent. In *Amphibia* and *Reptilia* there is nothing of the ordinary movements of inspiration and expiration as seen in the *Mammalia*. The air, indeed, is not inspired, but is swallowed. Further, the blood that passes to the respiratory organs is not wholly venous. It contains a considerable quantity of blood that does not require purification. Not only is the respiration inferior in quality to that encountered in birds and mammals, but it is deficient in quantity The number of respirations per minute in the members of these two slow-moving, slow-living classes, is much less than the number of respirations performed in a minute by one of the *Aves* or of the *Mammalia*.

(4) Turning to the highest class but one, we find the lungs much more completely divided. The bronchi, or first divisions of the trachea, run right through the lungs, giving off to right and left bronchial tubes of the first order, which, in their turn, give off secondary branches in their direct passage to the surface of the lungs. Birds do not swallow air like the cold-blooded classes. They have movements of inspiration and expiration, but those movements are dependent upon the muscles in connection with the ribs. *Aves* have no diaphragm, as *Mammalia* have. No longer in *Aves* does mixed blood pass through the respiratory apparatus. Venous blood only is constantly passing through the lungs. The number of respirations per minute is larger in this class than in any other. All the

above facts, and the last in especial, are connected with the activity of the bird's respiration. The following principle can scarcely be too frequently enunciated: The more frequent and powerful the movements of an animal, the more complete is its respiration—that is, the more frequently is the blood brought into relation with the air, and the greater is the extent of surface over which they meet. Finally, under *Aves*, in connection with this very principle, must be noted the extension of the respiratory apparatus into different regions of the body. It has been said that the bronchi and primary bronchial tubes pass right through the lungs into the body cavity. They are traceable ultimately into certain dilatations or air-sacs, nine in number: (i.) and (ii.) Cervical, in the neck, (iii.) and (iv.) right and left anterior thoracic, (v.) and (vi.) right and left posterior thoracic, (vii.) and (viii.) right and left abdominal, (ix.) formed by the coalescence of two tubes and resting on the apex of the wishing bone or os furculare. As this os furculare is formed of the two clavicles or collar bones, this ninth sac is called the inter-clavicular. From the air sacs, air tubes extend through all regions of the body, some even entering into the very bones. This arrangement calls to mind the tracheal system of insects—a class resembling birds in excessive activity of movement. It would not be fair, however, to say that this extension of the respiratory system was solely for the purpose of increased facility of breathing, inasmuch as the blood-vessels lining the extensions of these air tubes are frequently arterial in their nature. Clearly, no purification of blood takes place here. The arrangement is of use, however, in diminishing the specific gravity of birds during flight.

(5) Lastly, in *Mammalia* we have the most complete form of lung. Bronchial tubes divide and subdivide, and subdivide again, their countless branches ending in two or more dilatations called air sacs. Each air sac presents a number of depressions, the so-called air cells. On the one surface of these air cells is air, on the other capillaries containing venous blood. The movements of inspiration and expiration are largely due to the rising and falling of the diaphragm, whose descent increases, whose ascent diminishes, the capacity of the air-tight cavity wherein the lungs are enclosed.

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